Annotated Bibliography of Literature on Flue Gas Conditioning (1966-1980)

York Services Corp.
Stamford, CT

Prepared for

Environmental Protection Agency
Washington, DC

Dec 80

U.S. Department of Commerce
National Technical Information Service
NTIS

United States
Environmental Protection
Agency

Office of General Enforcement
Washington DC 20460

EPA-340/1-80-018
March 1981

PB81-200420

Stationary Source Enforcement Series

Annotated Bibliography of Literature on Flue Gas Conditioning (1966-1980)

PRODUCT OF:
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.
EPA-340/1-80-018

2.

3. RECIPIENT'S ACCESSION NO.
PB81 200420

4. TITLE AND SUBTITLE
Annotated Bibliography of Literature on Flue Gas Conditioning

5. REPORT DATE
December 1980

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
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8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS

York Services Corporation
One Research Drive
Stamford, CT 06906

10. PROGRAM ELEMENT NO.

11. CONTRACT/GRANT NO.
68-01-4138

12. SPONSORING AGENCY NAME AND ADDRESS

U. S. Environmental Protection Agency
Division of Stationary Source Enforcement
Washington, DC 20460

13. TYPE OF REPORT AND PERIOD COVERED
Final

14. SPONSORING AGENCY CODE

15. SUPPLE

16. ABSTRACT

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17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Flue gas conditioning, fly ash conditioning agents, low sulfur coal burning, high resistivity fly ash collection, particulate emission reduction, precipitator collection efficiency.		

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
	20. SECURITY CLASS *(This page)*	22. PRICE

EPA-340/1-80-018

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Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of General Enforcement
Division of Stationary Source Enforcement
Washington, DC 20460

March 1981

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ABSTRACT

This report presents a comprehensive bibliography of literature on Flue Gas Conditioning. It was developed through search of numerous data bases including Air Pollution Abstracts (APTIC), Chemical Abstracts, Engineering Index (COMPENDEX), Environmental Abstracts (ENVIROLINE), National Technical Information Service (NTIS), etc. Publications of Electric Power Research Institute, Edison Electric Institute and Department of Energy are also included. Information is provided on the assigned U.S. patents related to Flue Gas Conditioning. The literature is organized under four separate categories: (i) general theory, (ii) specific methods and agents, (iii) specific installations using FGC, and (iv) legal and regulatory aspects.

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ACKNOWLEDGEMENT

The authors are grateful to Mr. Timothy Dempsey of EPA library services for his assistance in searching useful data bases. A special note of thanks is due to Mr. Mark Antell, EPA Task Manager, for excellent coordination and help in support of our effort.

ANNOTATED BIBLIOGRAPHY OF LITERATURE ON FLUE GAS CONDITIONING

1.0 Introduction

Many coal-fired power plants are switching from high to low sulfur coal to meet sulfur dioxide emission regulations. However, low sulfur coal produces high resistivity fly ash which is difficult to collect by an electrostatic precipitator (ESP), and the utilities are faced with problems of excessive particulate emissions.

Flue Gas Conditioning (FGC) presents a potential solution to the problem of high resistivity fly ash collection. It usually involves the injection of a chemical into flue gas to control the electrical resistivity of the ash and improve its collection in an electrostatic precipitator. It may also serve two more purposes: (i) to increase the cohesiveness of fly ash particles deposited in a precipitator and (ii) to improve the electrical properties of the gas stream flowing between discharge wires and collection electrodes.

2.0 FGC Literature

A considerable amount of work has been done in this increasingly important area of particulate emissions control. Several different chemicals have been successfully used for conditioning. To develop a comprehensive bibliography on FGC literature, the following databases were searched through EPA library services:

a. Air Pollution Abstracts (APTIC)
b. Chemical Abstracts
c. Engineering Index (COMPENDEX)
d. Environmental Abstracts (ENVIROLINE)
e. National Technical Information Service (NTIS)

Publications of Electric Power Research Institute (EPRI), Department of Energy (DOE) and Edison Electric Institute (EEI) are also included in this report. York in-house library is a member of Southwestern Connecticut Library Council. It provided several useful citations and all patent information to complete the literature search.

The literature is organized under the following four separate categories:

a. General Theory

b. Specific Methods and Agents

c. Specific Installations using FGC

d. Legal and Regulatory Aspects

Many citations deal with more than one category and are, therefore, listed more than once under separate topics.

2.1 General Theory

Flue gas conditioning technology to reduce the fly ash resistivity has been known for more than fifteen years, in both the U.S. and Europe. However, it has gained significant importance only after 1970. Since then, considerable attention has been paid to this area by many private industries. Many research projects have been carried out to better understand the mechanism of FGC.

Flue gas conditioning has been extensively discussed in symposiums on particulate emissions control. This, along with the research work, has resulted in many publications on the subject. The citations listed in this section deal with the general theory of

FGC. They discuss the basic mechanisms of action of FGC as well as its various effects on fly ash, viz., resistivity modification, enhanced cohesiveness, and space charge effects. They also investigate the conditions under which good results are obtained and the common problems associated with its use. Each citation is accompanied by its abstract.

1. Aimone, R.J., Bourke, R.T., Stuparich, J.J., "Experience with Precipitators When Collecting Ash from Low Sulfur Coals", Presented at the 36th Annual Meeting of American Power Conference, Chicago, IL, April 1974.

   Abstract:

   This paper discusses many of the problems with precipitators when collecting fly ash from low sulfur coals. Also discussed are the techniques for combating these problems including relatively low gas velocity, use of suitable rapping method, high degree of electrical sectionalization, use of double half-wave power with automatic controls and flue gas conditioning.

2. Archer, William E., "Flyash Conditioning Update", Power Eng., Vol. 81, No. 6, June 1977.

   Abstract:

   An account is given of the use of flue gas conditioning by injecting trace amount of SO_3 into the flue gas stream ahead of the electrostatic precipitator in order to reduce the resistivity of the flyash to a level at which the precipitator can function normally.

3. Atkins, R.S., Rubernick, D.V., "Keeping Fly Ash Out of the Stack", Environmental Science and Technology, Vol. 12, No. 6, June 1978.

Abstract:

First, two engineers from a company long in the precipitator field explain the functions of these systems, and what some of the design and construction methodology is. Then two other engineers from EPA and a leading research institute tell how they tested a hot-side precipitator, and what they found.

4. Atkins, Richard S., and David H. Klipstein, "Improved Precipitator Performance by SO_3 Gas Conditioning", Natl. Eng., Vol. 79, No. 11, Nov. 1975.

Abstract:

Gas conditioning can dramatically improve the performance of electrostatic precipitators at relatively low cost. It can be applied to precipitators already in operation and to new units. It involves injecting small quantities of a chemical into the flue gas which optimizes the electrical resistivity of fly ash, making it more amenable to collection in a precipitator. Precipitator performance is discussed. Dust conductivity may be increased by small quantities of easily ionized chemicals called conditioning agents. Typically, conditioning compounds for each type of dust are found by educated trial and error. The most common conditioning agents are sulfuric acid and ammonia. There are several types of commercial sulfur trioxide gas conditioning systems: evaporation of liquid SO_3; catalytic conversion of sulfur dioxide; vaporization of sulfuric acid; and sulfur burning followed by the catalytic conversion of SO_2 to SO_3. The simplest is a liquid SO_3 gas conditioning system. Sulfuric acid is heated above its boiling point, vaporized, and diluted with air in acid vaporization. Then it is injected into the flue ahead of the precipitator. About 70 to 75% of SO_2 can be converted to SO_3 by catalytic conversion. The resultant mixture will then be injected into the flue gas. Sulfur burning is also described. In situ, portable test, mobile, and computer equipment is discussed. When switching to a lower sulfur fuel, existing precipitators are unlikely to maintain performance without either increased precipitator capacity, reduction in boiler operating rate, or gas conditioning.

5. Baxter, Walter A., "Recent Electrostatic Precipitator Experience with Ammonia Conditioning of Power Boiler Flue Gases", Journal of the APCA, Vol. 18, No. 12, December 1968.

Abstract:

This paper discusses experiments done by Koppers Company with ammonia conditioning of power boiler flue gases for the purpose of improving the precipitability of the emitted fly ash. Chemical reactions resulting from ammonia injection are postulated. Measurements on three pulverized coal and two cyclone fired boilers, all of which emit acidic ash, are described. In all five cases, considerable but varying, increase in precipitator power input and collection efficiency resulted when gaseous ammonia in the amount of 15 ppm was injected between the economizer and air preheater. The conditioned fly ash showed decreased acidity and inconsistent change in electrical resistivity. Unless air heater temperatures were unusually high (>400°F), the tendency of the air heater to plug was an additional, but unwanted, result.

At one station with a high air heater outlet temperature, ammonia injection has been adopted as a permanent solution to community pressure for a reduction of stack discharge. Ammonia injection downstream of the air heater produced no effect. Future plans are presented to continue the program beyond results described here.

6. Bennett, R.P., "Fly Ash Conditioning to Improve Precipitator Efficiency with Low Sulfur Coals", ASME Publication 76-WA/APC-8, December 1976.

Abstract:

The use of blended chemical agents to condition coal fly ash to improve electrostatic precipitator efficiency and reduce particulate emissions has been subjected to extensive field trials to verify its broad application as a possible economic solution to pollution problems for the electric utility industry. These chemical conditioning agents have been used with a variety of low to medium sulfur coals resulting in precipitator efficiency improvements of 50 to 90 percent. Emissions compliance levels are often obtained as a result of this treatment. The effectiveness of this system has been demonstrated on units from 25 to 750 MW. Case history examples illustrate the types of units treated and the extent of emissions reductions obtained.

7. Bennett, R.P., Kober A.E., "Chemical Enhancement of Electrostatic Precipitator Efficiency", Symposium on the Transfer and Utilization of Particulate Control Technology, EPA-600/7-790044a, February 1979.

Abstract:

It has been shown previously that chemical conditioning of flyash can offer an immediately available alternative to retrofit precipitators, baghouses, or other methods of mechanical collection and usually provides compliance emissions at relatively low operating cost. The equipment required involves minimum capital investment and can usually be installed in a matter of weeks with no significant unit downtime being involved.

It has now been demonstrated that the technique of chemical conditioning can be expanded into a previously untried area with the successful treatment of high-sulfur coals, of hot precipitators, and of low-sulfur coals utilizing a dual-injection system to provide minimum emissions and minimum opacity. Ready availability and minimum total costs are two advantages of this method. The use of new conditioning agents for these processes is continually being examined for further advances in the state of flue gas chemical conditioning.

8. Bickelhaupt, R.E., "Sodium Conditioning to Reduce Fly Ash Resistivity", EPA/650/2-74-092, October 1974.

Abstract:

The resistivity of fly ash is often too high under a particular set of operating conditions to permit the most efficient use of an electrostatic precipitator. A variety of substances, generally referred to as conditioning agents, can be added to the boiler or to the effluent gas downstream to attenuate the high resistivity. The report gives the results of a review of recent research, including the results of two field tests of sodium

conditioning, on the effects of sodium content on the electrical resistivity of coal fly ash. It presents a procedure for calculating the amount of sodium that must be added to reduce fly ash electrical resistivity to a desired value. It discusses advantages and disadvantages of sodium conditioning for reducing fly ash resistivity.

9. Bickelhaupt, R.E., "Effect of Chemical Composition on Surface Resistivity of Fly Ash", EPA/600/2-75-017, August 1975.

Abstract:

Electrical resistivity is one of the critical parameters influencing the collectability of fly ash by electrostatic precipitation. This report discusses research designed to acquire additional knowledge about the surface conduction process. Transference experiments revealed that the alkali metal ions serve as charge carriers. It was concluded that the attack by certain environmental species, water and acid, on the surface of the glassy ash mobilizes the alkali metal ions. A correlation was established between the magnitude of maxium surface resistivity and the concentrations of lithium, sodium, potassium and iron. The correlation offers a possible means of estimating the resistivity of an ash from the chemical analysis for a given set of environmental conditions.

10. Bickelhaupt, R.E., "Measure of Fly Ash Resistivity Using Simulated Flue Gas Environments", EPA/600/7-78/035, March 1978.

Abstract:

The report, describing the apparatus and laboratory procedures used to determine resistivity for a number of fly ashes under a variety of test conditions, supports research to develop a technique for predicting fly ash resistivity from chemical analyses of coal and coal ash. This effort requires considerable knowledge regarding the relationship between resistivity and several coal and ash properties. In particular, the report relates the experimental problems encountered when attempts were made to determine the effect of sulfur trioxide on resistivity. Equipment and procedures were developed to solve this problem. The report describes the modified apparatus and technique and illustrates the type of data acquired.

11. Bickelhaupt, R.E., Dismukes, E.B., Spafford, R.B., "Flue Gas Conditioning for Enhanced Precipitation of Difficult Ashes, Final Report", EPRI-FP-910, October 1978.

Abstract:

A review of the available prior investigations indicates that the effectiveness of ammonia and triethylamine as conditioning agents used to improve the performance of electrostatic precipitators has been inconclusive. When successful conditioning has occurred, it sometimes has been impossible to determine the process by which the conditioning agent affects the performance. The objective of this research was to examine the ability of these two conditioning agents with respect to the attenuation of resistivity and the suppression of back corona. Conventional resistivity determinations were made using simulated flue gas environments containing the subject agents. A second approach utilized a wire-guarded plate apparatus for the determination of voltage-current relationships. With regard to the effect these conditioning agents have on the electrical characteristics of a precipitator, the laboratory data suggest only an attenuation of resistivity. A mechanism by which these

agents enhance conduction is hypothesized. The usefulness of triethylamine and particulary ammonia is severely limited by temperature and ash composition. The effectiveness of both agents is also influenced by the sulfur oxides present. The voltage-current data suffered from several experimental difficulties. In general, the data support the observation that these agents are capable of reducing resistivity under certain limiting conditions. Experimental problems prevented the observation of space charge effects related to ammonia injection that have been identified during field testing performed by one of the authors and reported elsewhere.

12. Borsheim, R., Bennett, R.P., "Chemical Conditioning of Low Sulfur Western Coal", Presented at 39th Annual Meeting, American Power Conference, Chicago, IL, April 1977.

Abstract:

This paper gives the results of conditioning program carried out at Corette plant of Montana Power Company. Chemical conditioning of fly ash allowed boiler operating loads to be raised from an average of 148 MW to full 163 MW net load without exceeding particulate emissions and plume opacity limits.

13. Breich, E.W., "Flue Gas Conditioning for New Electrostatic Precipitators/An Economic Evaluation", Presented at the Symposium on the Transfer and Utilization of Particulate Control Technology, University of Denver, Denver, CO, July 24-28 1978.

Abstract:

This paper discusses the methods and associated costs of alternative collectors for the collection of low sulfur coal fly ash on an 800 MW unit. Systems evaluated

include: cold side precipitators, hot side precipitators, cold side precipitator with Flue Gas Conditioning, fabric filters, and flue gas desulfurization systems (scrubbers).

In the case of the scrubber, it is assumed that the fly ash is removed by either a precipitator system or fabric filter before entry into the scrubber for removal of sulfur oxides.

14. Breisch, E.W., "Method and Cost Analysis of Alternative Collectors for Low Sulfur Coal Fly Ash", Symposium on the Transfer and Utilization of Particulate Control Technology, EPA-600/7-79-044a, February 1979.

Abstract:

Flue Gas conditioning in conjunction with a conventionally sized precipitator is shown to be the most cost-effective means of collecting low sulfur coal, high resistivity fly ash. The results obtained with flue gas conditioning are both predictable and dramatic.

A case in point is the experience which Public Service Company of Colorado has had with vendors for their new 99.2% efficient precipitator installation at Arapahoe Station Unit 1. PSCC received bids from a number of vendors for hot side precipitators and for cold side precipitators with and without conditioning. The Specific Collecting Areas proposed ranged from 295 to 334.5 for the hot gas side precipitator. The bids for cold side ranged from an SCA of 688 with no conditioning, down to 279 with conditioning. PSCC chose the conditioned precipitator and after a year's operation of the combined installation, acceptance tests were conducted. The results were even better than the original conformance tests. Emissions in lb/MM BTU's were .0161; well below the statutory limit of .10. Average outlet grain loadings were only .0079 gr/dscf.

15. Brennan, H., Reveley, R.L., "Flue Gas Conditioning with Sulfur Trioxide to Improve Precipitator Performance", Proceedings of American Power Conference, Detroit Edison Company, Detroit, MI, 1977.

    Abstract:

    Unavailable

16. Brown, T.D., Lee, G.K., Reeve, J., Sekhar, N., "Improved Electrostatic Performance by Use of Flyash Conditioning Agents", Journal of the Institute of Fuel, Series 51, Issue 409, 1978.

    Abstract:

    Unavailable

17. Cheremisinoff, P.N., "Advanced Flyash Conditioning Technology", Power Engineering, November 1977.

    Abstract:

    Effects of high resistivity of flyash on the precipitator performance are discussed. Improvements in precipitator performance can be accomplished by new conditioning agents which not only control the conductivity of flyash but also increase the particle-to-particle cohesion and the space charge.

18. Cohen, Murray S., Bennett, R.P., "Case Studies on Chemical Flue Gas Treatment As A Means of Meeting Particulate Emission Regulations", ACS Symposium Ser., No. 109, Miami Beach, FL, September 14, 1978.

Abstract:

A description is given of the chronological development of two streams of Federal legislation, one regulating the emissions of particulates from large stationary sources and the other seeking to reduce the dependence upon foreign oil imports. It shows how these regulations offered an opportunity for the development and commercialization of a new technology called chemical Flue Gas Conditioning. An explanation is given of the operation of existing particulate control devices, notably the electrostatic precipitator (ESP). A description is also given of how particulate capturability can be improved by chemical treatment and then how a proprietary formulation has lead to the treatment of a wide variety of fuels in both cold and hot side ESP units is illustrated. Evidence is also presented showing that fine particular emissions, i.e., those implicated in health effects, could be significantly reduced.

19. Cook, R.E., "Sulfur Trioxide Conditioning", J. Air Pollution Control Association, Vol. 25, No. 2, February 1975.

Abstract:

Burning of western low sulfur coal, to reduce sulfur oxide emissions, has resulted in decreased electrostatic precipitator collection efficiencies. In an effort to restore precipitator performance a flue gas conditioning program was established. This paper discusses experience with sulfur trioxide as a flue gas conditioning agent. Testing at State Line Station has proven that sulfur trioxide conditioning can effectively be used to improve precipitator performance when burning low sulfur coals.

20. Dilt, P., Coughlin, R.W., "Improving Efficiency of Electrostatic Precipitation by Physicochemical Modification of the Electrical Resistivity of Flyash", AICHE Journal, Vol. 22, No. 4, July 1976.

Abstract:

Theory and experiment show that lowered resistivity of fly ash, frequently caused by adding conditioning agents to flue gas to improve efficiency of electrostatic precipitation, is caused by capillary condensation of liquid at the contact points of ash particles, thereby providing additional pathways for flow of electrical current.

21. Dismukes, E.B., "A Study of Resistivity and Conditioning of Fly Ash", EPA-R2-72-087, February 1972.

Abstract:

An experimental study was made on the injection of SO_3 and H_2SO_4 gaseous conditioning agent to alleviate the problem of high electrical resistivity of fly ash.

22. Dismukes, E.B., "Conditioning of Fly Ash with Sulfamic Acid, Ammonium Sulfate and Ammonium Bisulfate", EPA/650/2-74-114, October 1974.

Abstract:

The report summarizes recent experience with three agents--sulfamic acid, ammonium sulfate, and ammonium bisulfate--used to regulate the electrical resistivity of fly ash in electric generating stations to ensure satisfactory collection of fly ash in electrostatic precipitator (ESP's). It presents information about the effectiveness of theses agents in pilot- and full-scale ESP's. It also presents the limited information available from practical trials of these agents concerning their conditioning mechanisms. It discusses in detail the fundamental physical and chemical properties of the agents that are relevant to fly-ash conditioning. From this information and the results of ESP tests, the report offers tentative conclusions about conditioning mechanisms. Finally, the report briefly discusses the economic aspects of using each of the agents as a conditioning substitute for sulfur trioxide.

23. Dismukes, E.B., "Conditioning of Fly Ash with Ammonia", EPA-650/2-75-016, 1975.

Abstract:

Field tests at Tennessee Valley Authority coal-fired power plants involving the effect of flue gas conditioning with ammonia on the fly ash collection efficiency of electrostatic precipitators are described, with particular emphasis on the mechanisms of collection enhancement. Ammonia conditioning appears to improve the efficiency of fly ash precipitation through two mechanisms. The first consists of a space-charge effect, and the second involves an increase in the cohesiveness of fly ash. The first occurs with fly ash having low to moderately high resistivities, while the second mechanism is observed only with low-resistivity fly ash. Evidence of each mechanism is observed only under circumstances where the properties of the coal and the fly ash as well as the temperature of the flue gas permit significant concentrations of sulfur trioxide (2-11 ppm) to occur in the off gas. The reaction of ammonia with SO_3 to produce ammonium sulfate or ammonium bisulfate appears to be a key event in the occurrence of either conditioning process.

24. Dismukes, E.B, "Conditioning of Fly Ash with Sulfamic Acid", EPA-650/2-75-016, 1975.

Abstract:

Pilot plant and field tests of sulfamic acid flue gas conditioning for the reduction of fly ash resistivity and increased electrostatic precipitator collection efficiency are reviewed. Sulfamic acid appears to be a worthy substitute for sulfur trioxide as a flue gas conditioning agent, as evidenced by increases in collection efficiency obtained at various coal-burning plants with with high-resistivity fly as problems. The primary advantages of sulfamic acid are its ease of handling and freedom from hazard; the high cost of the chemical is its main disadvantage. The mechanisms by which sulfamic acid acts as conditioning agent are not clearly established.

25. Dismukes, E.B., "Conditioning of Fly Ash with Sulfur Trioxide and Ammonia", EPA-600/2-75-015, August 1975.

Abstract:

The use of sulfur trioxide and ammonia as flue gas conditioners to improve the electrostatic precipitation of fly ash generated in coal-burning power plants was investigated. The primary role of SO_3 in improving collection appeared to be related to a lowering of fly ash resistivity from the excessive values associated with ash from low-sulfur coals. Ammonia conditioning appeared to involve a space charge of the precipitator as well as an increase in the cohesiveness of the collected as at times. Satisfactory sites of injection were the flue gas ducts in locations upstream from the precipitator, upstream from the combination of a precipitator and mechanical collector, and between the two types of collectors. Fly ash was successfully conditioned at temperatures ranging from 110 to at least 160°C.

26. Dismukes, E.B., "Techniques for Conditioning Fly Ash", Conference on Particulate Collection Problems in Converting to Low Sulfur Coals, EPA 600/7-76-016, October 1976.

Abstract:

Conditioning of fly ash is discussed in connection with electrostatic precipitators from several points of view: the purposes served, the types of chemicals used, and their mechanisms of action. Major emphasis is given to resistivity modification with sulfur trioxide and other agents. Comments are also made on alternative conditioning mechanisms: increasing the cohesiveness of deposited fly ash to minimize reentrainment and improving the electrical properties of the flue gas to increase the efficiency of fly ash collection.

27. Dixit, S.N., Cuisia, D.G., "Additives for Coal", Combustion Vol. 49, No. 6, December 1977.

Abstract:

With proper selection and control of fuel additives, fireside treatment in operating power plant installations can produce beneficial effects. Using an advanced stack gas sampler and an acid dewpoint meter, several functions of coal additives were demonstrated during actual field application. Coal additives are capable of reducing acid additives are capable of reducing acid dewpoint temperature of the flue gas; hence, minimizing boiler cold end corrosion; and substantially reducing smoke density and particulate loadings of the stack. Moreover, it was shown that coal additive can modify the fireside deposits to a more desirable chemical composition.

28. "Flue Gas Conditioning", Environment Science and Technology, Vol. 12, No. 13, December 1978

Abstract:

Low sulfur coals are increasingly used because of stringent air pollution control restrictions on sulfur oxide emissions. However, low sulfur coals can present other problems, such as flyash that is hard to capture using an electrostatic precipitator. One solution to this problem is to inject a chemical into the flue gas to condition the flyash. Some recent developments indicate that full federal acceptance of the flue gas conditioning technology may not be too far off. Representative Paul Rogers (D-FLA) has requested that EPA investigate chemical conditioning with the possible goal of requiring flue gas treatment under authority granted the agency under the Clean Air Act of 1977. Several instances of the use of flue gas conditioning by U.S. companies are described.

29. Frisch, N.W., Dorchak, T.P, "Impact of Fuel on Precipitator Performance", Pollution Engineering, Vol. 10, No. 5, May 1978.

Abstract:

Variations in the chemical content of coal used as a fuel affect the ability of precipitators to remove particulates from flue gas resulting from coal combustion. For example, ash having a high electrical resistivity may require a much larger precipitator than ash of a low resistivity requires. High resistivity ash may shorten the component life of precipitators. Precipitator performance must be considered in assessing fuel sources, and optimal conditions must be provided to achieve an appropriate resistivity level for the fuel chosen. The roles of conductive agents, ash conditioning, and coal blending in analysis of coal for plant performance are explored. Resistivity data are graphed.

30. Green, G.P., "Operating Experience with Particulate Control Devices", Presented at the American Society of Mechanical Engineers, Air Pollution Control Division, National Symposium, 3rd, Philadelphia, PA, April 1973.

Abstract:

Operating experience associated with the control of particulate emissions from steam plant units burning low sulfur, high resistivity, western coals is reviewed. Initially disappointing collection efficiencies with electrostatic precipitators were improved by conditioning the flue gas with sulfur trioxide such that its concentration in the gas to be treated was 20 ppm. Collection efficiencies for eight different units ranged from 37.5-94.0% before flue gas conditioning and from 51.2-97.2% after conditioning with SO_3.

31. Jaworowski, R.J., O'Connor, M.J., "Effect of Flue Gas Conditioned Fly Ash on Electrostatic Precipitator Control", Procurement of the ISA Conference and Exhibition, Philadelphia, PA, October 15-19, 1978.

Abstract:

Electrostatic precipitators (ESP) are designed for a specific combination of dust fineness, resistivity, and concentration. The ability of the ESP to cope with changes in these parameters is limited and significant reductions in performance often accompany changes in coal supplies (high sulfur coal to low sulfur coal to reduce SO_2 emissions). This paper discusses the use of precipitator control readings to diagnose problems resulting from changes in fly ash resistivity, particle size distribution, and concentration. The use of chemical conditioning agents to overcome the adverse effects of these changes is discussed and examples of successful applications are given.

32. Kanowski, S., Coughlin, R.W., "Catalytic Conditioning of Fly Ash Without Addition of SO_3 from External Sources", Environmental Science Technology, Vol. 11, No. 1, January 1977.

Abstract:

Data and experimental results are presented to demonstrate that catalytic oxidation of sulfur dioxide (SO_2) at the low concentrations normally present in flue gas from low sulfur coal can produce sulfur trioxide SO_3 in concentrations sufficiently large to cause good conditioning by significantly lowering the resistivity of fly ash. This was accomplished by disposing catalysts in streams of SO_2 bearing flue gas and measuring the effects of the gases so treated on the resistivity of carbon-free fly ash obtained from several different coal-fired power stations. Concentrations of SO_2 and SO_3 were measured by gas sampling and chemical analysis. The effects of moisture and temperture were also investigated.

33. Klipstein, D.H., "Improved Precipitator Performance by Gas Conditioning", Combustion Vol. 47, No. 4, October 1975.

Abstract:

The switching from high sulfur to low sulfur Western coals -should they become available- will reduce SO_2 problems but add flyash removal problems. One solution, discussed in this article, is the role of gas conditioning which involves the injection of small quantities of SO_3 into the flue gas to reduce electrical resistivity of fly ash, thus making the dust more amenable to collection in the precipitator. The fundamentals of electrostatic precipitators are reviewed, and several types of commercial SO_3 gas conditioning systems are examined both from the technical and economic standpoint.

34. Kropp, L.I., Shmigol, I.N., Chekanov, G.S., Oglesby, S., Bickelhaupt, R.E., "Joint US/USSR Test Program for Reducing Fly Ash Resistivity", Journal of the APCA, Vol. 29, No. 6, June 1979.

Abstract:

An electrostatic precipitator preceded by a wet scrubber was tested at the Reftinskaya Power Station. The unit collects a high resistivity fly ash from the combustion of low sulfur Ekibastuz coal. The operating parameters of the precipitator were measured as well as the mass emissions and the in-situ electrical resistivity of the fly ash. Density, particle size distribution, electrical resistivity, and chemical composition were determined for collected samples of the fly ash. The fly ash was also characterized by X-ray diffraction and scanning electron microscopy. When a centrifugal wet wall scrubber was installed ahead of the electrostatic precipitator, the temperature of the flue gas entering the precipitator was decreased and the moisture content increased. The electrical resistivity of the fly ash was reduced by a factor of 10, but not enough to overcome the adverse effects of back corona in the precipitator. Lowering the flue gas temperature to about 85°C by the addition of a venturi scrubber ahead of the centrifugal scrubber reduced the electrical resistivity of the fly ash by another factor of 10 and allowed the operation of the precipitator without back corona.

35. Kukin, I., "Utilization of Additives in Controlled Combustion Products", Presented at the MECAR Technical Symposium on Combustion and Air Pollution Control, October 25, 1966.

Abstract:

Practical applications of chemical additives for reducing air pollution with petroleum fuels are discussed. Successful results have been achieved in the field by the use of additives for fuel oils, both distillate and residual fuels. The major pollutants are: (1) black particulate matter representing primarily unburned hydrocarbons: (2) sulfur oxides (SO_2 and SO_3). With distillate fuels, where the sulfur content generally is below 0.5%, our primary concern is particulate matter and to a somewhat lesser degree, carbon monoxide, aldehydes and nitrogen oxides. With residual fuels, sulfur, as SO_2 and SO_3, is the dominant consideration, although the ability to reduce black smoke emission by means of chemical additive is certainly a valuable contribution to air pollution control. The three effective classes of chemical additives are: (1) combustion catalysts, (2) oil-ash slag modifiers, and (3) chemical neutralizing agents. In some cases, these chemical agents can be combined to give one or more benefits. In a recent trial at a power plant, one of their products, SSI-3(R), reduced the black smoke at the same time that it lowered the SO_3 content of the flue gas from 90 to 5 parts per million. The case histories cited show how chemical additives are being used to reduce air pollution and, at the same time, make a contribution to better overall fuel utilization.

36. Kukin, I., "Advances In The Use Of Chemical Treatment In Air Pollution Reduction Programs", Presented at the National Petroleum Refiners Association Rocky Mountain Region Meeting, Billings, MT, October 2-3, 1968, Paper RM-68-80.

Abstract:

Extensive in-plant tests were made on the ability of a fuel additive containing 25% activated manganese to keep boiler fireside tubes clean and to reduce the sulfur trioxide content of the flue gas. Especially good results were obtained in pressurized furnace of 2500 psig when low sulfur fuel oil (one percent) was burned. After three months, the treated furnace showed a 75% reduction in the SO_3 content of the flue gas and only slight tar deposits were apparent. The deposits could be brushed off rapidly, even by simple air lancing. Since the smaller quantities than is the ash with magnesium oxide additives. The manganese additive is not stoiciometrically consumed in reactions with vanadium and sulfur oxides but regenerates itself. It reacts with carbons and hydrocarbons to increase the carbon dioxide content of the flue gas; it further lowers the ignition temperature of combustible deposits within a furnace. By eliminating soot, it improves the appearance of stacks. Another factor favoring the use of the additive is that it reduces the excess air to fuel ratio.

37. Kukin, I., "Additives Can Clean Up Oil-Fired Furnaces", Environmental Science Technology 1973, Vol. 7, No. 7, July 1973.

Abstract:

The addition of metal-containing additives to improve boiler cleanliness, cut fireside and air heater corrosion, and to reduce stack emissions and plumes is discussed. In general, fuel additives should provide boiler cleanliness, high-temperature vanadium corrosion protection, prevention of loss of operating capacity by maintaining design steam temperature, cold end (air heater) corrosion protection, reduction of stack emissions from hydrogen particulate matter and sulfur trioxide, and improvement in the handling characteristics of ash in the flue gas in oil fired boilers equipped with precipitators and stack collectors. The significant fuel additives in use today usually contain magnesium oxide (with or without small amounts of aluminum oxide or hydrate), manganese, and magnesium oxide with manganese. The characteristics of each of these additives is discussed, and the efficacy of magnesium oxide additives is compared to that of manganese additives. Handling characteristics and air emissions are also reviewed.

38. Kukin, I., "Effects of Additives On Boiler Cleanliness and Particulate Emissions", Procurement Int. Meet. Soc. Eng. Sci., 1st, Tel Aviv, Israel, 1972.

Abstract:

Concentrated metal-containing additives are often used in oil-fired furnaces to improve boiler cleanliness and reduce the fireside and air heater corrosion. They can also reduce stack emissions, especially hydrocarbon particulates and sulfur trioxide. They can improve the handling characteristics of the ash in the flue gas in oil-fired boilers equipped with precipitators and stack collectors. Significant fuel additives in use today contain magnesium oxide, manganese, or magnesium oxide with manganese. The role of MgO as a fuel oil additive with high sulfur and high vanadium fuels is described. Low sulfur-low vanadium fuels often contain manganese additives. High temperature slagging and corrosion in oil-fired boilers is reduced with a slurry containing both

MgO and Mn in combination. Manganese additives reduce internal boiler fouling of superheaters and reheaters at low ash input ratios. High sulfur fuels with low Vanadium content are preferably treated with tail end chemical injection of an active neutralizing agent to remove SO_3. Overall decrease in stack emission ideally is obtained with a dual additive application consisting of addition of Mn to the fuel oil and a neutralizing agent to the economizer outlet. Manganese additives eliminate stack smoke, particularly in refineries burning pitch or polymerized bottoms. Corrosion and fouling from SO_3 in coil-fired units can be eliminated by aspirating an activated neutralizing agent in powder form into the economizer outlet of the furnace. Other uses of additives are discussed.

39. Kukin, I., Bennett, R., "Chemical Control of Particulate Emissions Through Flue Gas Conditioning", Presented at 12th Conference on Air Quality Management in the Electric Power Industry, The University of Texas at Austin, TX, January 28-30, 1976.

<ins>Abstract:</ins>

This paper shows how the use of chemicals has become a valuable, relatively simple and quickly installed method for helping coal burning units to meet emissions regulations. Faced with uncertain fuel supplies and handicapped by a capital shortage, the electric utility industry can look to increased use of sophisticated chemical technology for solutions to pollution problems. The proper application of chemical additives can allow utilities to meet emission standards related to particulates and plume opacity, at the same time often allowing for improved efficiency and reduced fuel usage.

40. Kukin, I., Bennett, R., "Particulate Emission Control Through Chemical Conditioning", Combustion Vol. 48, No. 4, October 1976.

Abstract:

The chemical treatment of flue gases to reduce polluting emissions was subjected to quantitative field tests to verify its practicality as a possible economic solution to current energy and pollution problems for electric utilities. Chemical conditioning agents for the ash in the flue gas improved electrostatic precipitator collection efficiency by 50-90%, so that the units complied with emission regulations. Some units have been able to operate at increased capacity while still meeting compliance levels. Chemical neutralization of SO_3 in the flue gas, resulting in a lowered acid dew point, allows operation at reduced exit gas temperatures. Reduced particulate emissions frequently result from this safe change in operation.

41. Kukin, I., Bennett, R.P., "Chemical Reduction of SO_3, Particulates and NO_x Emissions, J. Inst. Fuel, Vol. 50, No. 402, March 1977.

Abstract:

The chemical treatment of fuels and flue gas to reduce polluting emissions was subjected to quantitative fields tests to verify its practicality as a possible economic solution to current energy and pollution problems for electric utilities. Manganese added to a residual fuel oil at 50 ppm reduced sulphur trioxide emissions by up to 55%. Manganese has also been effective in reducing nitrogen oxide emissions by as much as 31%. Chemical conditioning agents for the ash in the flue gas of coal-fired units were used to improve electrostatic precipitator

precipitator collection efficiency by 50-90%, so that the units complied with emission regulations. Examples from case histories illustrate how environmental protection can be obtained, at least with regard to SO_3, particulates and NO_x, without incurring large capital expense.

42. Kukin, I., Nelson, H., "The Economics of Chemical Conditioning for Improved Precipitator Performance", Public Util. Forth, September 23, 1976.

Abstract:

The result of power companies switching from over 2% sulfur content coal to low sulfur coal has frequently been a reduction of electrostatic precipitator efficiency, resulting in particulate emissions exceeding limits. Chemical treatment can bring the resistivity of fly ash to the level required for high efficiency operation of the electrostatic precipitator. The multifunctional systems capable of optimizing fly ash resistivity, flue gas space charge, and fly ash particle size distribution are the most effective. Case histories illustrate the ability of these chemcial systems to obviate the need for multimillion dollar precipitator retrofits. Further benefits are to be expected in new plant designs, where savings in capital and operating costs of chemically treated fly ash permit use of smaller, lower cost electrostatic precipitators.

Flue gas-fly ash conditioning systems do not contribute sulfur oxides to stack gases.

43. Lederman, P.B., Bibbo, P.B., Bush, J., "Chemical Conditioning of Fly Ash for Hot-Side Precipitation", Symposium on the Transfer and Utilization of Particulate Control Technology, EPA 600/7-79-044a, February 1979.

Abstract:

The concerns over universal application of hot precipitators to certain low alkali, low sulfur western coals, which emerged when performance problems on a few installations in the west were encountered (Columbia, Comanche, Hayden), have now been eliminated with the development of practical and proven hot precipitator conditioning technology. Sodium conditioning has been proven in the field as the chemical modifier of choice for hot precipitators. It is economically attractive compared to other means of upgrading marginal precipitators. This technology should be considered for new units to provide conditioned precipitator units capable of operating on difficult ashes, with the added benefit of some SO_x removal, at lower costs than systems not utilizing chemical conditioning.

44. Livengood, C.D., Farber, P.S., Wong, S.H., "Environmental Control Strategies for Coal-Fired Power Plants: A Comparative Evaluation", National conference on energy and the environment, Cincinnati, OH, USA, 31 October 1977.

Abstract:

An ongoing project has been established at Argonne National Laboratory for the purpose of assessing the implications of environmental control technologies for the coal-to-electricity process from a detailed engineering and cost point of view. In order to place these assessments in the proper perspective, it is helpful to conduct comparative evaluations of their effectiveness from a total system viewpoint, taking into account different geographic, environmental, and regulatory constraints. This paper presents some of the results of the initial comparisons carried out by the project. The focus is on control of airborne emissions by presently available technology, as this has been the principal area of investigation thus far. The results point out that there are usually several cost-competitive routes to achieving compliance with existing regulations. However, these routes generally have differing total impacts, particularly offsite, which will become of greater significance as new regulations force lower levels of on-site effluents.

45. Martin, G.B., D.W. Pershing, and E.E. Berkau, "Effects of Fuel Additives on Air Pollutant Emissions from Distillate-Oil-Fired Furnaces", Environmental Protection Agency, Research Triangle Park, NC, Office of Air Programs, Pub-AP-87, June 1971.

Abstract:

The use of fuel additives to control air pollution from distillate-oil-fired systems was examined. The additives tested were commercially available, proprietary formulations; each additive was analyzed for chemical composition and was screened for effect on emission characteristics. Fewer than 10% of the additives affected any pollutant reduction, whereas more than 20% increased emissions of at least one pollutant. In a few cases, metallic additives substantially reduced particulate emissions, but produced a high concentration of metal compounds in the flue gas. Additives did not reduce emissions of carbon monoxide, unburned hydrocarbons, sulfur oxides, or nitrogen oxides.

46. Matts, S., "Cold-Side Electric Precipitators for High-Resistivity Fly Ash Require Different Design Philosophy", EPA-650/2-75-016, 1975.

Abstract:

European versus American designs for electrostatic precipitators are discussed in economic terms, with particular reference to the use of cold-side electrostatic precipitators for the collection of high-resistivity fly ash. Below a certain temperature of the flue gas being treated, the dust components absorb increasing amounts of moisture, resulting in a decrease in resistivity. The peak resistivity occurs around 150°C, i.e., close to normal operating temperatures after the air heater. Cold-side precipitator operation using less-sectionalized European precipitators is more economical than hot-side precipitator operation for American fly ashes.

47. McIlvaine, R.W., "New Developments and Trends in Air Pollution Control Equipment", Filter Sep, Vol. 17, No. 1, January-February 1980.

Abstract:

In fabric filtration, developments include a hybrid precipitator fabric filter, use of a fabric filter with spray tower to remove SO_2 to recoverable products, commercialization of electrostatically augmented scrubbers, and improvements in corrosion resistant materials. Developments in electrostatic precipitators include precharging devices, new flue gas conditioning techniques, and methods of charging. The importance of these new techniques and predictions for future use are discussed.

48. McRanie, R.D., J.M. Craig, and G.O. Layman, "Evaluation of Sample Conditioners and Continuous Stack Monitors for the Measurement of Sulfur Dioxide, Nitrogen Oxides and Opacity in Flue Gas from A Coal-Fired Steam Generator", Southern Services, Inc., Birmingham, AL, Research Department, February 1975.

Abstract:

The effectiveness of sample conditioners and continuous stack monitors for the measurement of sulfur dioxide, nitrogen oxides, and opacity in flue gas from a coal-fired steam generator is reported. Individual evaluations of the seven sample conditioners, nine SO_2 analyzers, nine NO_x analyzers, and two opacity monitors included are presented. Analyzer accuracy and sample conditioner influence testing formed an integral part of the evaluation. Reliable and accurate continuous stack monitoring systems cannot be purchased off the shelf from any manufacturer. They must be specified to sample conditioner recommended for use on a coal-fired steam generator. It seems to have no effect on the components of interest in flue gas. The analyzers determined to be most satisfactory with the SSI sample conditions for SO_2 are DuPont, Mine Safety Appliances, and Beckman; for NO_x Thermo Electon and DuPont, and for opacity Lear Siegler. Design and operation recommendations for a monitoring system are included and the analytical techniques used in continuous stack monitoring are discussed.

49. Midkiff, L.A., "Flue-Gas Conditioning Upgrades Performance, Cuts Down Size of Precipitators", Power Vol. 123, No. 4, April 1979.

Abstract:

Chemical enhancement of precipitator efficiency, once limited to low-sulfur retrofit applications, is now being designed into new units. Flue gas conditioning techniques, their mechanisms,and uses are described. Flue-gas conditioning began with the use of moisture to lower ash resistivity. Today's techniques, however, include modification of particle size, and of the space charge in the gas phase. Hot-side as well as cold-side precipitators can often benefit from flue gas treatments that are properly applied. Flyash with a resistivity of 10^9-10^{10}ohm-cm is considered ideal for collection. Methods of lowering the resistivity of the dust, such as the use of a hot-side precipitator, or chemical conditioning in the cold-side precipitator, are discussed. Low-resistivity conditioning and space-charge conditioning are finally described.

50. Morris, E.B. and J.L. Schumann, "Condition Flyash with Synthetic SO_3", Power, Vol. 118, No. 7, July 1974.

Abstract:

The conditioning of fly ash with synthetic sulfur trioxide is discussed. It enables an electrostatic precipitator to achieve normal collection efficiencies when cleaning flue gas from boilers burning low sulfur, high ash coals. The injection of minute quantities of SO_3 reduces the electrical resistivity of the fly ash to values below the critical level of 10^{10} ohms-cm. These SO_3 quantities range from 10 to 30 ppm by volume of the flue gas. On site synthesis eliminates the need for storing or handling either sulfuric acid or liquid SO_3. It is more economical than installing new hot precipitators, wet scrubbers, or special low temperature electrostatic precipitators designed for low sulfur coal. Existing plants can upgrade the collection efficiency of their electrostatic precipitators to meet new particulate codes while continuing to burn economical low sulfur coal.

51. Nekervis, R., J. Pilcher, J. Varga Jr., B. Gonser, and J. Hallowell, "Process Modifications for Control of Particulate Emissions from Stationary Combustion, Incineration, and Metals (Final Report)", EPA-650/2-74-100, October 1974.

Abstract:

The state of process modifications for controlling fine particulate emissions from stationary combustion sources (electrical utilities and industrial processes), municipal incinerators, iron and steel plants, ferro-ally plants, and nonferrous metal smelters (zinc plants, copper smelters, and aluminum reduction cells) is reviewed. Modifications to conventional stationary combustion sources considered include: ash fluxing, sulfur trioxide addition to flue gas, staged combustion, the use of fuel additives, fly ash agglomeration, solvent refining, and flue gas recirculation. Unconventional systems studied include: fluidized beds, coal gasification, and submerged combustion. Combined flue-refuse firing, gas cooling, and pyrolysis methods are considered for incinerators. Emphasis for iron and steel plants is given to the bottom-blowing oxygen process. Modification of the conventional reverberatory smelting procedure and the introduction of hydrometallurgical methods are discussed for copper. The chloride electrolytic process by the Aluminum Company of America is considered with respect to its stage of development, availability or acceptability by industry, efficiency in reducing emissions, and environmental impact.

52. Oglesby, S., Jr., Nichols, G.B., "Electrical Resistivity and Conditioning (Chapter 7)", Electrostatic Precipitation, Marcel Dekker, Inc., New York, 1978.

Abstract:

Electrical resistivity of the dust influences electrostatic precipitators (ESP's). If the dust has high resistivity in a single stage precipitator, the corona current will be limited, reducing precipitator performance. The force holding the dust layer to the collecting plant can be large with high resistivity dust, and high intensity rapping is required. Such conditions can result in larger than normal reentrainment. High electrical resistivity of the dust can result in sparkover or back corona. Increased thickness of the dust layer can cause a change from a back corona to a sparking condition for the same dust. The variations in current are such that the maximum allowable current is lower by about a factor of ten than predicted from theoretical considerations. Volume resistivity and temperature are inversely related at high temperatures. Surface conduction, occurring at lower temperatures, depends upon gaseous reaction with the particles and the composition and morphology of the particles. Conduction above about 250°C is controlled by an ionic mechanism and related to the alkali metals in the ash. Surface resistivity is governed principally by the potassium or sodium and lithium ion concentration. Empirical relationships are given for determining the surface resistivity of ashes. Hot precipitators operate at 600-800°F, where the resistivity is usually low enough that precipitator electrical conditions are not severely limited by breakdown of the dust layer. However, about 50% greater gas volume must be handled. Dust resistivity can be altered changing the ash or flue gas composition. Moisture conditioning, sulfur trioxide conditioning, ammonia additions, and other conditioning agents are discussed.

53. Ostrovski, O.P., Y.I. Chander, Y.N. Reznikov, L.N. Gulaga, V.V. Martynenko, A.N. Timofeev, E.P. Mezentsev, I.P. Shkinder, "Flue Gas Dust Recovery In Electrostatic Precipitators Improved With An Additive To The Fuel Oil", Refractories Vol. 18, No. 1-2, January-February 1977.

Abstract:

When rotary kilns are fired with sulfurous fuel oil, the electrostatic precipitators do not function efficiently owing to the formation of a solid layer of dust on the electrodes. As a result of high resitivity, the layer of magnesite and dolomite dust on the precipitation electrodes acts as an insulator so that the current decreases sharply and an "inverse corona" is formed. The formation of solid deposits is attributable to the sulfurous and chlorous compounds in the material being fired. An effective method of reducing dust deposits and increasing the efficiency of the dust extraction process consists of using the fuel additive VNIINP-106.

54. Patterson, R., Riersgard, R., Parker R., Sparks, L.E., "Flue Gas Conditioning Effects on Electrostatic Precipitators", Symposium on the Transfer and Utilization of Particulate Control Technology, EPA-600/7-79-044a, February 1979.

Abstract:

Flue gas conditioning agents are used primarily for maintaining high particulate collection efficiency in electrostatic precipitators operating on high resistivity fly ash from low sulfur coals. Burning low sulfur coals has been a popular method for meeting sulfur dioxide emissions limits. Flue gas conditioning is rarely designed into a new installation; rather, it is normally used as a corrective method for an ailing precipitator.

Many conditioning agents have been investigated for improving the collection efficiency of ESP's. When injected, the conditioning agents mix with the gas to form various gaseous and particulate compounds, depending on the flue gas composition and temperature. This program is designed to determine the improvement in ESP performance and the additional gaseous and particulate compounds which penetrate the ESP.

55. Paulson, C.A., Potter, E.C., Kahanne, R., "New Ideas on Precipitation Technology from the Csiro Combustion Rig", Presented at the Changing Technology of Electrostatic Precipitation Symposium, 1974.

Abstract:

A pilot scale coal burning electrostatic precipitation rig is described and its use for assessing the precipitation behavior of fly ash is explained. A method of plotting dust collection efficiencies against a combined function of specific collection area and applied voltage has been developed, which yields a performance line for the precipitator handling a given dust under stated conditions of temperature and carrier gas composition. The performance lines permit the comparison of the precipitation behavior of fly ashes from different coals, and are useful in assessing flue gas additives and in estimating the design size of full scale precipitators from pilot plant observations. The additives investigated include ammonia, sulfur trioxide, trimethylamine, triethylamine, and cyclohexylamine. The performance lines show that triethylamine at trace levels improves precipitator performance dramatically with difficult fly ashes, the improvement being due to agglomeration of suspended dust and raising of breakdown voltage. Some other additives, particularly cyclohexylamine, worsen precipitator performance by lowering breakdown voltage and dispersive natural dust agglomerates.

56. Petersen, H.H., "Conditioning of Dust with Water-Soluble Alkali Compounds", Symposium on the Transfer and Utilization of Particulate Control Technology, EPA-600/7-79-044a, February 1979.

Abstract:

A comparison of resistivity measurements and chemical analyses of dusts from cement rotary kilns has shown a close relationship between resistivity and the content of water-soluble alkali compounds. Laboratory experiments comprising impregnation of high resistivity dust samples with various water-soluble alkali salts confirmed that small quantities of alkali compounds were sufficient to reduce the resistivity considerably. This led to full scale experiments at a precipitator installation treating high resistivity dust from a preheater kiln at a cement plant in Brazil. Here an aqueous solution of potassium sulfate was injected, atomized and evaporated in the gas stream before the precipitator. An 0.4% increase in water soluble K_2O reduced the resistivity of the dust from 10^{13} to 10^{11} ohm-cm and a corresponding improvement in precipitator performance was observed. Recent additional full scale conditioning experiments with potassium sulfate and sodium chloride at a precipitator installation after a coal-fired lime kiln in South Africa yield similar results.

57. Radway, J.E., "Effectiveness of Fireside Additives in Coal-Fired Boilers", Power Engineering, April 1978.

Abstract:

Benefits of using fireside additives in coal-fired boilers are discussed. A case history is also presented. In addition to aiding emission control and providing for greater flexibility in coal use, chemical treatment may improve operating reliability and increase boiler availability.

58. Roehr, J.D., "Flue Gas Conditioning Cold and Hot Precipitators", Presented at the Southeastern Electric Exchange Meeting, New Orleans, Louisiana, April 16-18, 1980.

Abstract:

This paper discusses the reasons for using flue gas conditioning, the various methods and agents used and the expected operating costs. Several agents or chemicals have been used to achieve conditioning, such as ammonia, water, sodium, sulfuric acid, etc. Proprietary compounds are on the market and are also being used. Some of these conditioning alternatives are outlined here.

59. Schwarz, R.C., "Superior Fuel Oil Additives Carry Good Engineering Credentials", National Engineering, Vol. 76, No. 8, August 1972.

Abstract:

The choice of a proper fuel oil additive for the particular problems that beset an individual boiler is a difficult task. Before making a choice, one should know what types of additives are available, what mechanism each uses to function, and possible environmental complications that can result from the use of each. The many additives on the market fall into four general groups: deposition control agents, combustion catalysts, sludge solubilizers, and water emulsifiers. Each of these functions is discussed. Various metal compounds in fuel oil additives include aluminum, barium, copper, lead, magnesium, and manganese. Points worth serious consideration in evaluating an additive supplier are listed. The condensation of sulfur trioxide can cause fouling of the heat recovery elements by a boiler system. Additives can reduce sulfur dioxide coversion to SO_3. Combustion reduce carbon particulates such as ash in flue gas.

60. Selle, S.J., Hess, L.L., Sondreal, E.A., "Western Fly Ash Composition as an Indicator of Resistivity and Pilot ESP Removal Efficiency", Presented at the Air Pollution Control Association, Annual Meeting, 68th, Boston, MA, June 15-20, 1975, Paper 75-02.5.

Abstract:

Pilot-scale electrostatic precipitator performance tests were run on a high and low resistivity western fly ash and mixtures thereof. The fly ashes were collected from full-scale electrostatic precipitator hoppers and reentrained in a flue gas of constant analysis ahead of a 120 scf/min pilot precipitator. Fly ash composition and measured resistivity were good indicators of precipitator performance.

Reentrained high sodium fly ash acted as an electrostatic precipitator conditioning agent for high resistivity fly ash.

The addition of only 0.75% of the high sodium fly ash increased the effective migration velocity from 0.5 to 0.8 ft/sec at 300°F. Similar results were obtained at 475°F. Computer regression analysis correlating laboratory fly ash resistivity with chemical analysis substantiated the inverse relationship between resistivity and sodium oxide content of the fly ash.

61. Spafford, R.B., Dismukes, E.B., Dillon, H.K., "Analysis of Thermal Decomposition Products of Flue Gas Conditioning Agents", EPA/600/7-79-179, August 1979.

Abstract:

The report gives results of a study of reactions of several flue gas conditioning agents in a laboratory-scale facility simulating conditions in the flue gas train of a coal-burning power plant. Primary purposes of the study were to characterize the chemical species resulting from adding conditioning agents to flue gas and to identify potentially hazardous chemical species originating from the agents that may be emitted into the environment. The compounds investigated were sulfur trioxide, ammonia, triethylamine, sodium carbonate, ammonium sulfate, and diammonium hydrogen phosphate. The predominant types of reactions observed in these experiments were thermal decomposition fragments at lower temperatures, and reactions with normal components of the flue gas. The only significant environmental threat of any product identified during this study was the formation of N-nitrosodiethylamine as the result of injecting triethylamine into the flue gas. This potent carcinogen was found in trace amounts when triethylamine was injected at 160°C.

62. Sparks, L.E., "Electrostatic Precipitators Options for Collection of High Resistivity Fly Ash", Conference on

Particulate Collection Problems in Converting to Low Sulfur Coals, EPA-600/7-76-016, October 1976.

Abstract:

An analysis of the technical options for collecting high resistivity fly ash is presented. The options are a large specific collection area at low temperatures (about 150°C), a wet electrostatic precipitator, a moderate to large specific collection area electrostatic precipitator operating at either high (about 370°C) or low temperature (about 110°C), or a moderate specific collection area for an electrostatic precipitator operating at normal temperature with fly ash conditioning. The advantages and disadvantages of each option are discussed. The potential for adverse environmental impact of the conditioning option is also discussed.

63. Steelhammer, J.C., Polizzotti, D.M., Graffeo, A.J., "Electrostatic Precipitators: Gas Conditioning", AICHE Symposium Series, Series 74, Issue 175, 1978.

Abstract:

Unavailable

64. Steelhammer, J.C., Nogash, D.R., Mangravite, F.J., Graffeo, A.J., Terry, J.P., Harpel, W.L., "Effect of Chemical Additives on Electrostatic Precipitator Performance", Presented at the Purdue Air Quality Conference, Annual, 14th, November 12-13, 1975.

Abstract:

Field evaluations of the effect of various chemical additives on electrostatic precipitator performance were performed. The coal used throughout the experiments contained between 2 and 3% sulfur, 20-25% ash, and 5-7% mixture. The chemical additives were fed to the flue gas as aqueous solutions, and the chemical feed system consisted of several air atomizing spray nozzles. The chemical additives were fed to the flue gas for approximately 1-3 hours before particulate sampling was started. Increases in precipitator collection efficiency were obtained with one organic and two inorganic additives. Efficiencies of 96.4%, 95.3%, and 94,9%, respectively, were obtained with the additives as compared to a control efficiency of 91.9%. The increased efficiencies appeared to be due to space charge effects and cohesivity modification.

65. Technology Update, "Fuel Additives: The Bottom Line for Energy Savings and Pollution Control", Plant Energy Management, March/ April 1978.

Abstract:

Because of rising fuel costs, many industrial plants are converting to cheaper, less desirable fuel. This conversion can create problems unless these fuels are somehow treated. This paper shows how fuel additives can be used to solve the problems of slag, corrosion, and air pollution control.

66. Troupe, J.S., "Handwriting on the Power Plant Wall-Flue Gas Treatment", Combustion, Vol. 50, No. 4, October 1978.

Abstract:

The more important points of flue gas treatment technology are addressed. Control of particulate matter and sulfur dioxide is discussed. The capital cost of flue gas cleaning may be about 20% of the cost of the entire power plant. SO_2 control can account for 65-75%.

67. Tseluiko, Yu. I., Chander, Yu. I., Borisovskii, L.M., "Ammonia Added to the Gas-and-Dust Emission of Rotary Kilns as a Factor in the Performance of the Electrical Precipitators", Refractories, Vol. 16, No. 11-12, November-December 1975.

Abstract:

Electrical precipitators are the most efficient gas scrubbers used in the refractories industry. The degree of dust entrapment by these devices depends on their design and electrical regime and on the properties of the gas and dust mixture emitted by the kiln. The resistivity, i.e., specific electrical resistance (SER), of the dust is a significant factor in the performance of the precipitator. Conditioning the flue gas with ammonia reduces the SER of the dust so that the degree of dust entrapment in electrical precipitators increases, especially when the flue gas contains a large proportion of sulfur oxides. Conditioning is at optimum with a 3-6% ammonia solution and an ammonia consumption of 4-5 kg per 100,000 m^3 flue gas.

68. Walker, A.B., "Characteristics and Electrostatic Collection of Particulate Emissions from Combustion of Low Sulfur Western Coals", Presented at the Air Pollution Control Asociation, Annual Meeting, 67th, Denver, CO, June 9-13, 1974, Paper 74-11.

Abstract:

About 90% of the known strippable low-sulfur coal reserves in the U.S. are in the area west of the Mississippi River. These coals can meet sulfur oxide emission regulations without the need for flue gas desulfurization. The principal use of these coals will be as fuel for conventional boilers which will require particulate removal efficiencies in excess of 99%. The

emission characteristics and electrostatic precipitator performance tests on these coals are desribed. Mass emissions as a percentage of fuel ash were somewhat lower than Eastern bituminous coals, but there was insufficient information to suggest deviation from currently available methods, based upon Eastern coals, for predicting ash carryover. Size distribution of particulate emissions on pulverized coal units was similar to that of Eastern bituminous coal. However, size distribution of particulates from Western coals in cyclone boilers was somewhat coarser that from the same fuel in pulverized coal units or predicted from available data on Eastern bituminous coals burned in cyclone boilers. Bulk electrical resitivity of Western fuel ash at typical air heater outlet temperatures varied over a wide range, could not be predicted on the basis of fuel sulfur alone, and generally was above the level where back corona would be expected. The bulk electrical resistivity of Western fuel ash, at typical air heater inlet temperatures, varied over a narrower range with most of the cases encountered being below the level where back corona would be expected. Precipitator performance can generally be correlated according to a modified form of the Deutsch equation. This indicates that specific collecting electrode areas in the range of 350-550 sq ft/1000 acfm are required for achievement of 99% collection efficiency on fly ash with in-situ resistivity levels in the range of 10^{10}-10^{12} ohm-cm; and that specific collecting areas as high as 900-1000 sq ft/1000 acfm may be required to achieve efficiencies in the 99.8% range.

69. Watson, K.S., "Australian Experience with Flue Gas Conditioning", Particulate Control in Energy Processes, EPA 600/7-76-010, September 1976.

Abstract:

Australian black coal fired in power stations usually contain less than 1% sulfur and has 15 to 30% ash. Target emission levels for new plants are often better than 0.1 gm/m^3 at NTP requiring collection efficiencies of 99.5%. Highly resistive fly ash predicates specific collecting areas in excess of 80 m^2/m^3/s (400 ft^2/1000 cfm) for cold precipitators. Early precipitators frequently had specific collecting areas of less that 50 m^2/m^3/s and performed badly. Gas conditioning has been regularly used to improve collection efficiencies since the middle 60's and to date has been provided on 26 precipitators on boilers from 25 to 500 MW capacity and totalling over 4,000 MW.

Steam and/or water temperature modification, P_2O_5, NH_3, and SO_3 were used experimentally from 1955 onwards. Sulfuric acid was first used operationally in 1964 and anhydrous ammonia has been used since 1965. Triethylamine was first used in 1975 and is currently being evaluated.

The effect of reagents varies from station to station and is also dependent on precipitator type and reagent concentration. Considerable care must be given to the injection system to allow proper mixing and sufficient resident time. Improvements of migration velocity in excess of 300% have been attained with SO_3/H_2SO_4 and in excess of 200% with ammonia, which is perferred reagent because of its relative safety and convenience. Triethylamine appears to be even more effective than SO_3.

Comparatively few operational problems have been reported and most can be traced to over-conditioning or to poor distribution. Capital costs range from 0.05 to 0.12 $/KW and operating costs fom 0.01 to 0.05 mils/KW-hr depending on the reagent and injection concentration.

70. White, H.J., "Electrostatic Precipitation of Fly Ash, Fly Ash and Furnance Gas Characteristics (Part II, Section 3)", J. Air Pollution Control Association, Vol. 27, No. 2, February 1977.

Abstracts:

Fly ash and furnace gas characteristics that affect design and performance of electrostatic precipitators are discussed. The composition, temperature, and pressure of the gas govern the basic corona characteristics of the precipitator, while particle size, particle concentration, and electrical resistivity of the fly ash affect both the corona and the particle collection properties. The gas flow volume rate is also fundamental to precipitator design and performance. The chemical compositions of different kinds of coal and of typical furnace gases are present in the precipitator. The presence of sulfur trioxide (SO_3) in the flue gas greatly reduces the electrical resistivity of the fly ash, by raising the dewpoint of the flue gas. Problems with high resistivity can be caused by the use of low sulfur coals; responses include the location of precipitators ahead of, rather than after, the air preheater, where gas temperatures of 600 to 800°F are sufficiently high to overcome problems of high resistivity. The chemical analysis of fly ash is presented from the literature. Particle size distributions of ash from power plants are given. The measurement and significance of particle size and the resistivity of fly ash are discussed.

2.2 Specific Methods and Agents

Several chemicals have been successfully used on coal-fired utilities to improve the collection efficiency of electrostatic precipitators. There are about five major suppliers of FGC systems in the U.S.A. In most of the cases, the conditioning agent is injected into the flue gas in the form of a liquid spray, often between the air preheater and the ESP. Sometimes, it is injected in the furnace. Sulfur trioxide, sulfuric acid, ammonia, sodium and ammonium compounds are some of the commonly used conditioning agents. In addition, there are many proprietary chemicals whose compositions are kept confidential.

The literature cited in this section deals with the use and effects of the specific agents. Many references give information on the particulate emissions before and after conditioning. Limitations to the use of specific agents and some common difficulties are also discussed.

1. Archer, William E., "Flyash Conditioning Update", Power Eng., Vol. 81, No. 6, June 1977.

   Abstract:

   An account is given of the use of flue gas conditioning by injecting trace amounts of SO_3 into the flue gas stream ahead of the electrostatic precipitator in order to reduce the resistivity of the flyash to a level at which the precipitator can function normally.

2. Atkins, Richard S., and David H. Klipstein, "Improved Precipitator Performance by SO_3 Gas Conditioning", Natl. Eng., Vol. 79, No. 11, Nov. 1975.

Abstract:

Gas conditioning can dramatically improve the performance of electrostatic precipitators at relatively low cost. It can be applied to precipitators already in operation and to new units. It involves injecting small quantities of a chemical into the flue gas which optimizes the electrical resistivity of fly ash, making it more amenable to collection in a precipitator. Precipitator performance is discussed. Dust conductivity may be increased by small quantities of easily ionized chemicals called conditioning agents. Typically, conditioning compounds for each type of dust are found by educated trial and error. The most common conditioning agents are sulfuric acid and ammonia. There are several types of commercial sulfur trioxide gas conditioning systems: evaporation of liquid SO_3; catalytic conversion of sulfur dioxide; vaporization of sulfuric acid; and sulfur burning followed by the catalytic conversion of SO_2 to SO_3. The simplest is a liquid SO_3 gas conditioning system. Sulfuric acid is heated above its boiling point, vaporized, and diluted with air in acid vaporization. Then it is injected into the flue ahead of the precipitator. About 70 to 75% of SO_2 can be converted to SO_3 by catalytic conversion. The resultant mixture will then be injected into the flue gas. Sulfur burning is also described. In situ, portable test, mobile, and computer equipment is discussed. When switching to a lower sulfur fuel, existing precipitators are unlikely to maintain performance without either increased precipitator capacity, reduction in boiler operating rate, or gas conditioning.

3. Baxter, Walter A., "Recent Electrostatic Precipitator Experience with Ammonia Conditioning of Power Boiler Flue Gases", Journal of the APCA, Vol. 18, No. 12, December 1968.

Abstract:

This paper discusses experiments done by Koppers Company with ammonia conditioning of power boiler flue gases for the purpose of improving the precipitability of the emitted fly ash. Chemical reactions resulting from ammonia injection are postulated. Measurements on three pulverized coal and two cyclone fired boilers, all of which emit acidic ash, are described. In all five cases, considerable but varying, increase in precipitator power input and collection efficiency resulted when gaseous ammonia in the amount of 15 ppm was injected between the economizer and air preheater. The conditioned fly ash showed decreased acidity and inconsistent change in electrical resistivity. Unless air heater temperatures were unusually high (>400°F), the tendency of the air heater to plug was an additional, but unwanted, result. At one station with high air heater outlet temperatures, ammonia injection has been adopted as a permanent solution to community pressure for reduction of stack discharge. Ammonia injection downstream of the air heater produced no effect. Future plans are presented to continue the program beyond results described here.

4. Bennett, R.P., "Fly Ash Conditioning to Improve Precipitator Efficiency with Low Sulfur Coals", ASME Publication 76-WA/APC-8, December 1976.

Abstract:

The use of blended chemical agents to condition coal fly ash to improve electrostatic precipitator efficiency and reduce particulate emissions has been subjected to extensive field trials to verify its broad application as a possible economic solution to pollution problems for the electric utility industry. These chemical conditioning agents have been used with a variety of low to medium sulfur coals resulting in precipitator efficiency improvements of 50 to 90 percent. Emissions compliance levels are often obtained as a result of this treatment. The effectiveness of this system has been demonstrated on units from 25 to 750 MW. Case history examples illustrate the types of units treated and the extent of emissions reductions obtained.

5. Bennett, R.P., Kober A.E., "Chemical Enhancement of Electrostatic Precipitator Efficiency", Symposium on the Transfer and Utilization of Particulate Control Technology, EPA-600/7-790044a, February 1979.

Abstract:

It has been shown previously that chemical conditioning of flyash can offer an immediately available alternative to retrofit precipitators, baghouses, or other methods of mechanical collection and usually provides compliance emissions at relatively low operating costs. The operating equipment required involves minimum capital investment and can usually be installed in a matter of weeks with no significant unit downtime being involved.

It has now been demonstrated that the technique of chemical conditioning can be expanded into a previously untried area with the successful treatment of high-sulfur coals, of hot precipitators, and of low-sulfur coals utilizing a dual-injection system to provide minimum emissions and minimum opacity. Ready availability and minimum total costs are two advantages of this method. The use of new conditioning agents for these processes is continually being examined for further advances in the state of flue gas chemical conditioning.

6. Bickelhaupt, R.E., "Sodium Conditioning to Reduce Fly Ash Resistivity", EPA/650/2-74-092, October 1974.

Abstract:

The resistivity of fly ash is often too high under a particular set of operating conditions to permit the most efficient use of an electrostatic precipitator. A variety of substances, generally referred to as conditioning agents, can be added to the boiler or to the effluent gas downstream to attenuate the high resistivity. The report gives results of a review of recent research, including the result of two field tests of sodium conditioning, on the effects of sodium content on the electrical resistivity of coal fly ash. It presents a procedure for calculating the amount of sodium that must be added to reduce fly ash electrical resistivity to a desired value. It discusses advantages and disadvantages of sodium conditioning for reducing fly ash resistivity.

7. Bickelhaupt, R.E., Dismukes, E.B., Spafford, R.B., "Flue Gas Conditioning for Enhanced Precipitation of Difficult Ashes, Final Report", EPRI-FP-910, October 1978.

Abstract:

A review of the available prior investigations indicates that the effectiveness of ammonia and triethylamine as conditioning agents used to improve the performance of electrostatic precipitators has been inconclusive. When successful conditioning has occurred, it sometimes has been impossible to determine the process by which the conditioning agent affects the performance. The objective of this research was to examine the ability of these two conditioning agents with respect to the attenuation of resistivity and the suppression of back corona. Conventional resistivity determinations were made using simulated flue gas environments containing the subject agents. A second approach utilized a wire-guarded plate apparatus for the determination of voltage-current relationships. With regard to the effect these conditioning agents have on the electrical characteristics of a precipitator, the laboratory data suggest only an attenuation of resistivity. A mechanism by which these agents enhance conduction is hypothesized. The usefulness of triethylamine and particulary ammonia is severely limited by temperature and ash composition. The effectiveness of both agents is also influenced by the sulfur oxides present. The voltage-current data suffered from several experimental difficulties. In general, the data support the observation that these agents are capable of reducing resistivity under certain limiting conditions. Experimental problems prevented the observation of space charge effects related to ammonia injection that have been identified during field testing performed by one of the authors and reported elsewhere.

8. Borsheim, R., "Flyash Conditioning Brings Particulate Emissions Into Compliance", Power Eng., Vol. 81, No. 1, January 1977.

Abstract:

Low sulfur coal has unfavorable consequences on the performance of an electrostatic precipitator. Electrical resistivity of the fly ash, fly ash particle size distribution, and space charge affect the performance of the electrostatic precipitator in a coal burning power plant. Fly ash conditioning involves injecting an agent into the flue gas, making the fly ash more collectible by the electrostatic precipitator. One commercial additive lowers the electrical resistivity of the fly ash by adsorbing some conductive species on the surface of the particles. When the Corette Power Station started burning coal containing 0.7 to 0.9% sulfur and 8 to 10% ash, the electrostatic precipitator performance was insufficient to meet particulate emission standards at all loads, and the unit was operated up to 16% below its load rating in order to comply. Mechanical and electrical improvements increased efficiency somewhat, but did not permit full-power operation. Opacity was measured constantly. Pre-trial testing in the 148 to 150 MW range gave opacity readings between 30 and 40%. Opacity levels dropped to 15 to 18% within 4 hr after the start of treatment. The amount of generation lost by derating was extremely high. Chemical treatment allowed boiler operating loads to be raised from an average of 148 MW to full load without exceeding particulate emissions and plume opacity limits. The cooling system used prior to treatment deprived the unit of combustion air. Cooling is not longer necessary to maximize precipitator performance. Cost of the treatment is less than 40 cent/ton of coal. This technology makes possible high collection efficiencies on existing equipment at modest prices.

9. Breich, E.W., "Flue Gas Conditioning for New Electrostatic Precipitators/An Economic Evaluation", Presented at the Symposium on the Transfer and Utilization of Particulate Control Technology, University of Denver, Denver, CO, July 24-28, 1978.

Abstract:

This paper discusses the methods and associated costs of alternative collectors for the collection of low sulfur coal fly ash on an 800 MW unit. Systems evaluated include: cold side precipitators, hot side precipitators, cold side precipitator with Flue Gas Conditioning, fabric filters, and flue gas desulfurization systems (scrubbers).

In the case of the scrubber, it is assumed that the fly ash is removed by either a precipitator system or fabric filter before entry into the scrubber for removal of sulfur oxides.

10. Breisch, E.W., "Method and Cost Analysis of Alternative Collectors for Low Sulfur Coal Fly Ash", Symposium on the Transfer and Utilization of Particulate Control Technology, EPA-600/7-79-044a, February 1979.

Abstract:

Flue gas conditioning in conjunction with a conventionally sized precipitator is shown to be the most cost-effective means of collecting low sulfur coal, high resistivity fly ash. The results obtained with flue gas conditioning are both predictable and dramatic.

A case in point is the experience which Public Service Company of Colorado has had with vendors for their new

99.2% efficient precipitator installation at Arapahoe Station Unit 1. PSCC received bids from a number of vendors for hot side precipitators and for cold side precipitators with and without conditioning. The Specific Collecting Areas proposed ranged from 295 to 334.5 for the hot gas side precipitator. The bids for cold side ranged from an SCA of 688 with no conditioning, down to 279 with conditioning. PSCC chose the conditioned precipitator and after a year's operation of the combined installation, acceptance tests were conducted. The results were even better than the original conformance tests. Emissions in lb/MM BTU's were 0.0161; well below the statutory limit of 0.10. Average outlet grain loadings were only 0.0079 gr/dscf.

11. Brines, H.G., Reveley, R.L., "Flue Gas Conditioning To Reduce Size and Costs of a New Precipitator at PSCC Arapahoe Station Unit No. 1", Proc. Am. Power Conf., Vol. 40, Chicago, IL, April 24-26, 1978, Sponsored by Ill. Inst. of Technol. Chicago, 1978.

Abstract:

This paper is a case history of the design and selection of a new cold-side electrostatic precipitator installation, working with a flue gas conditioning system at the Arapahoe Station Unit 1, Public Service Company of Colorado (PSCC). The installation is guaranteed to meet particulate emission regulations and performance criteria of the design specifications for a particulate control device. Unit No. 1 at Arapahoe is a steam/electric generating unit rated at 44,000 KW. It has a Babcock & Wilcox steam generator and ball mills and was designed to burn coal or gas. The generating unit was installed in 1950. Until the precipitator was installed, it was equipped with only a mechanical dust collector.

12. Brown, T.D., Lee, G.K., Reeve, J., Sekhar, N., "Improved Electrostatic Performance by Use of Flyash Conditioning Agents", Journal of the Institute of Fuel, Series 51, Issue 409, 1978.

Abstract:

Unavailable

13. Cheremisinoff, P.N., "Advanced Flyash Conditioning Technology", Power Engineering, November 1977.

Abstract:

Effects of high resistivity flyash on the precipitator performance are discussed. Improvements in precipitator performance can be accomplished by new conditioning agents which not only control the conductivity of flyash but also increase the particle-to-particle cohesion and the space charge.

14. Cohen, Murray S., Bennett, R.P., "Case Studies on Chemical Flue Gas Treatment As A Means of Meeting Particulate Emission Regulations", ACS Symposium Ser., No. 109, Miami Beach, FL, September 14, 1978.

Abstract:

A description is given of the chronological development of two streams of Federal legislation, one regulating the emissions of particulates from large stationary sources and the other seeking to reduce the dependence upon foreign oil imports. It shows how these regulations offered an opportunity for the development and commercialization of a new technology called chemical flue *gas conditioning. An explanation is given of the* operation of existing particulate control devices, notably the electrostatic precipitator (ESP). A description is also given of how particulate capturability can be improved by chemical treatment and then how a proprietary formulation has lead to the treatment of a wide variety of fuels in both cold and hot side ESP units is illustrated. Evidence is also presented showing that fine particular emissions, i.e., those implicated in health effects, could be significantly reduced.

15. Cragle, S.H., "Operating Experience with ESP Conditioning In Relation to an Electrostatic Precipitator Upgrading Program", Conference on Particulate Collection Problems in Converting to Low Sulfur Coals, EPA-600/7-76-016, October 1976.

Abstract:

This report summarizes the major areas of an ongoing electrostatic precipitator (ESP) upgrading program at Pennsylvania Power and Light Company. Particular emphasis is placed on the area of flue gas conditioning including eighteen months of operating experience with Apollo Chemical Corporation products, a planned SO_3 injection trial, and other potential agents.

Results of ongoing trials of Apollo products at Montour SES on two 750 MW bituminous coal fired units are presented. Performance data, operating problems and cost information are covered. Eight chemical formulations have been injected into various combinations of four locations in efforts to improve product performance, solve air heater plugging problems, and improve distribution of the product on the fly ash. A significant reduction of emissions on a difficult fly ash has been noted although only half as great a reduction as originally expected based on tests run with a good collecting fly ash. Air heater plugging problems have been eliminated.

The report also covers some of the practical considerations and potential problems that can occur in evaluating proprietary additives.

Also, the report briefly summarizes projects on six of the Company's ESP's including work in the following areas: fuel quality effects; flue gas conditioning; rappers; voltage controls; sectionalizing; gas flow distribution; operation and maintenance; and additional dust collector capacity.

16. Cook, R., Trykoski, M., "Sulfur Trioxide Injection at State Line Station", EPA-600/7-76-016, October 1976.

Abstract:

Commonwealth Edison's efforts to overcome the problem of electrostatic precipitator degradation through the use of sulfur trioxide (SO_3) flue gas conditioning is described. An analysis of the coal (low sulfur) being burned in Edison boilers revealed that the coal fly ash, with its higher resistivity, reduces the current flow between the electrodes of the electrostatic precipitator, and therefore the precipitator performance is reduced when compared to operation on high-sulfur coal. Evaluation of the Edison generating system showed that a total of 22 precipitators on ten generating units ranging in size from

120 to 620 MW would suffer degradation while burning low sulfur coal to the point where they could no longer meet particulate emission standards while operating at full load. Flue gas conditioning was sought as a means of restoring precipitator efficiency through the lowering of fly ash resistivity. Test results showed a dramatic improvement in precipitator performance with flue gas conditioning. Problems related to startup and miscellaneous boiler and precipitator effects are noted. Flue gas conditioning systems have not alleviated the other operating problems associated with the burning of low sulfur coal, but they are enabling these units to meet particulate emission standards with minimal derating at a cost far less than that of the only other feasible alternatives, major precipitator rebuild or a new precipitator.

17. Cook, R.E., "Sulfur Trioxide Conditioning", J. Air Pollution Control Association, Vol. 25, No. 2, February 1975.

Abstract:

Burning of western low sulfur coal, to reduce sulfur oxide emissions, has resulted in decreased electrostatic precipitator collection efficiencies. In an effort to restore precipitator performance a flue gas conditioning program was established. This paper discusses experience with sulfur trioxide as a flue gas conditioning agent. Testing at State Line Station has proven that sulfur trioxide conditioning can effectively be used to improve precipitator performance when burning low sulfur coals.

18. Dismukes, E.B., "A Study of Resistivity and Conditioning of Fly Ash", EPA-R2-72-087, February 1972.

Abstract:

An experimental study was made on the injection of SO_3 and H_2SO_4 gaseous conditioning agents to alleviate the problem of high electrical resistivity of fly ash.

19. Dismukes, E.B., "Conditioning of Fly Ash with Sulfamic Acid, Ammonium Sulfate and Ammonium Bisulfate", EPA/650/2-74-114, October 1974.

Abstract:

The report summarizes recent experience with three agents--sulfamic acid, ammonium sulfate, and ammonium bisulfate--used to regulate the electrical resistivity of fly ash in electric generating stations to ensure satisfactory collection of fly ash in electrostatic precipitator (ESP's). It presents information about the effectiveness of these agents in pilot- and full-scale ESP's. It also presents the limited information available from practical trials of these agents concerning their conditioning mechanisms. It discusses in detail the fundamental physical and chemical properties of the agents that are relevant to fly-ash conditioning. From this information and the results of ESP tests, the report offers tentative conclusions about conditioning mechanisms. Finally, the report briefly discusses the economic aspects of using each of the agents as a conditioning substitute for sulfur trioxide.

20. Dismukes, E.B., "Conditioning of Fly Ash With Ammonia", Journal of the APCA, Vol. 25, No. 2, February 1975.

Abstract:

This paper presents the results of an investigation of the conditioning of fly ash with ammonia in electrostatic precipitators of power plants operated by the Tennessee Valley Authority. It focuses attention primarily on the mechanisms of conditioning encountered under the particular circumstances available for study. No effect of ammonia on the electrical resistivity of fly ash was evident. Instead, the effect of ammonia appeared to be an enhancement of the space-charge component of the electric field used for charging and precipitating particles of fly ash. In addition, a second effect appeared to be an increase in the cohesiveness of precipitated ash and a reduction in the quantity of ash reentrained during electrode rapping. Data demonstrating the value of ammonia conditioning for lowering the emission of fly ash during three precipitator studies are presented. Reasons for the ineffectiveness of ammonia conditioning during a fourth precipitator study are discussed. In conclusion, comments are made about the effects to be expected from ammonia conditioning under circumstances different from those investigated experimentally, particularly with ammonia as a conditioning agent for fly ash from low sulfur western coal.

21. Dismukes, E.B, "Conditioning of Fly Ash with Sulfamic Acid", EPA-650/2-75-016, 1975.

Abstract:

Pilot plant and field tests of sulfamic acid flue gas conditioning for the reduction of fly ash resistivity and increased electrostatic precipitator collection efficiency are reviewed. Sulfamic acid appears to be a worthy substitute for sulfur trioxide as a flue gas conditioning agent, as evidenced by increases in collection efficiency obtained at various coal-burning plants with high-resistivity fly ash problems. The primary advantages of sulfamic acid are its ease of handling and freedom from hazard; the high cost of the chemical is its main disadvantage. The mechanisms by which sulfamic acid acts as a conditioning agent are not clearly established.

22. Dismukes, E.B., "Conditioning of Fly Ash with Sulfur Trioxide and Ammonia", EPA-600/2-75-015, August 1975.

Abstract:

The use of sulfur trioxide and ammonia as flue gas conditioners to improve the elctrostatic precipitation of fly ash generated in coal-burning power plants was investigated. The primary role of SO_3 in improving collection appeared to be related to a lowering of fly ash resistivity from the excessive values associated with ash from low-sulfur coals. Ammonia conditioning appeared to involve a space charge of the precipitator as well as an increase in the cohesiveness of the collected ash at times. Satisfactory sites of injection were the flue gas ducts in locations upstream from the precipitator, upstream from the combination of a precipitator and mechanical collector, and between the two types of collectors. Fly ash was successfully conditioned at temperatures ranging from 110 to at least 160°C.

23. Dismukes, E.B., "Techniques for Conditioning Fly Ash", Conference on Particulate Collection Problems in Converting to Low Sulfur Coals, EPA 600/7-76-016, October 1976.

Abstract:

Conditioning of fly ash is discussed in connection with electrostatic precipitators from several points of view: the purposes served, the types of chemicals used, and their mechanisms of action. Major emphasis is given to resistivity modification with sulfur trioxide and other agents. Comments are also made on alternative conditioning mechanisms, increasing the cohesiveness of deposited fly ash to minimze reentrainment, and improving the electrical properties to flue gas to increase the efficiency of collection.

24. Dismukes, E.B., Gooch, J.P., "Fly Ash Conditioning With Sulfur Trioxide", EPA/600/2-77/242, December 1977.

Abstract:

The report describes an evaluation of an SO_3 injection system for the George Neal Unit 2 boiler of the Iowa Public Service Company in Sioux City, Iowa. Results of base line tests without conditioning indicate a dust resistivity of 6 x 10 to the 12th power ohm-cm at 118°C; the precipitator's average collection efficiency was 91.3% at a specific collecting area of 42.8 sq $m^2/(m^3/sec)$. Because transformer-rectifier sets tripped out, apparently due to ash buildup in the hoppers, only one precipitator efficiency test was conducted with SO_3 system operating continuously with all T-R sets operating. Results of this test were: (1) specific collecting area = 41.8 $m^2/(m^3/sec)$; (2) collection efficiencies = 99.27% (ASME method), 98.96% (EPA method), and 98.78% (EPA method, including first impinger residue); and (3) 4 x 10 to the 10th power ohm-cm dust resistivity at 143°C. An adequate accounting was made for the fate of the injected SO_3.

25. Engel, W. and M. Meyerkord, "Flue Gas Conditioning at Wisconsin Power & Light to Improve Hot-side Precipitator Performance", Presented at the Seventh Annual Technical Conference of the Air Pollution Control Association, Midwest Section, Kansas City, Missouri, May 22-23, 1980.

Abstract:

To meet emission standards for sulfur dioxide, an increasing number of power plants have turned to western low-sulfur coal. While this has several technical and economic advantages, the fly ash released upon burning these coals is unfavorable in certain installations for adequate collection by electrostatic precipitators (ESPs). Reasons for this unfavorable performance have been related to high electrical resistivity of fly ash and relatively high proportion of small particle fly ash.

The cold side precipitator is still the most common means of particulate collection, especially for plants constructed before the early '70s. Hot-side precipitators are designed to eliminate the problem of high fly ash resistivity. The concept of the hot-side ESP was based on the correlations observed between sulfur content in coal, flue gas temperature, and fly ash resistivity. Fly ash resistivity drops sharply at elevated temperatures. Placement of the precipitator prior to the air heater where gas temperatures are typically 600-800°F, helps to overcome the resistivity problems. Many precipitators perform adequately in this mode. Certain low-sulfur coals, however, continue to produce a fly ash chemistry detrimental to precipitator operation, despite the higher flue gas temperature.

This phenomenon was experienced when Wisconsin Power & Light Company's Columbia Station Unit #1 went on line in the latter half of 1975. WP&L planners designed the unit around utilization of low-sulfur western coal, selecting hot-side electrostatic precipitation as the means of controlling fly ash emissions.

Chemical flue gas conditioning, a technology that has been effective in upgrading the efficiency of cold side electrostatic precipitators, has been successfully developed to overcome fly ash collection problems on hot side ESPs. Known commercially as the Coaltrol HPC system, this new flue gas conditioning system for hot-side precipitators has been applied at Columbia Station, enabling the plant to continue to comply with opacity and emission requirements.

26. Ferrigan, J.J., III, and J.D. Roehr, "SO_3 Conditioning for Improved Electrostatic Precipitator Performance Operating on Low Sulfur Coal," Proceedings of the Symposium on the Transfer and Utilization of Particulate Control Technology, Denver, Colorado, 1979.

Abstract:

This presentation deals with a case study of a particular utility's dilemna of having to choose an efficient and reliable air pollution control device to lower stack emissions on an existing unit. The paper traces the study from the time when excessive emissions required MW load deratings into the decision making process, the testing stage, and finally into the installation of SO_3 flue gas conditioning.

It points out why, in this particular case, SO_3 flue gas conditioning is a more reasonable choice than the installation of a new cold side precipitator or fabric filter baghouse. It clearly shows via test results supplied by a utility based in upstate New York that SO_3 flue gas conditioning enables units at their power plant to operate well within the legal standards enforced by the New York State Department of Environmental Conservation (NYSDEC).

27. Green, G.P., "Operating Experience with Particulate Control Devices", Presented at the American Society of Mechanical Engineers, Air Pollution Control Division, National Symposium, 3rd, Philadelphia, PA, April 1973.

Abstract:

Operating experience associated with the control of particulate emissions from steam plant units burning low sulfur, high resistivity, western coals is reviewed. Initially disappointing collection efficiencies with electrostatic precipitators were improved by conditioning the flue gas with sulfur trioxide such that its concentration in the gas to be treated was 20 ppm. Collection efficiencies for eight different units ranged from 37.5-94.0% before flue gas conditioning and from 51.2-97.2% after conditioning with SO_3.

28. Green, G.P., Landers, W.S., "Operating Experience With Gas Conditioned Electrostatic Precipitators", United States-USSR Working Group, Stationary Source Air Pollution Control Technology, Control Fine-Part., Emiss. Ind. Sources Symposium Proc., San Francisco, CA, 1974, January 15-18, Paper 8.

Abstract:

The effect of flue gas conditioning on the fly ash collection efficiency of eight electrostatic precipitators installed on pulverized coal burning units of the Public Service Company of Colorado is reported. The addition of 15-20 ppm of sulfur trioxide directly to the flue gas before the electrostatic precipitator increased collection efficiencies from a range of 37.5-94.0% for the eight units prior to gas conditioning to a range of 51.4-96.2%. The low efficiencies prior to SO_3 treatment were due to the high resistivity of the untreated fly ash (10 to the 13 ohm-cm) which in turn was due to the fact that the plant burns low sulfur western coal. Gas conditioning did not compensate for design deficiencies other than the resistivity problem.

29. Jaworowski, R.J., O'Connor, M.J., "Effect of Flue Gas Conditioned Fly Ash on Electrostatic Precipitator Control", Procurement of the ISA Conference and Exhibition, Philadelphia, PA, October 15-19, 1978.

Abstract:

Electrostatic precipitators (ESP) are designed for a specific combination of dust fineness, resistivity, and concentration. The ability of the ESP to cope with changes in these parameters is limited and significant reductions in performance often accompany changes in coal supplies (high sulfur coal to low sulfur coal to reduce SO_2 emissions). This paper discusses the use of precipitator control readings to diagnose problems resulting from changes in fly ash resistivity, particle size distribution, and concentration. The use of chemical conditioning agents to overcome the adverse effects of these changes is discussed and examples of successful applications are given.

30. Kanowski, S., Coughlin, R.W., "Catalytic Conditioning of Fly Ash Without Addition of SO_3 from External Sources", Environmental Science Technology, Vol. 11, No. 1, January 1977.

Abstract:

Data and experimental results are presented to demonstrate that catalytic oxidation of sulfur dioxide (SO_2) at the low concentrations normally present in flue gas from low sulfur coal can produce sulfur trioxide SO_3 in concentrations sufficiently large to cause good conditioning by significantly lowering the resistivity of fly ash. This was accomplished by disposing catalysts in streams of SO_2 bearing flue gas and measuring the effects of the gases so treated on the resistivity of carbon-free fly ash obtained from several different coal-fired power stations. Concentrations of SO_2 and SO_3 were measured by gas sampling and chemical analysis. The effects of moisture and temperature were also investigated.

31. Kropp, L.I., Shmigol, I.N., Chekanov, G.S., Oglesby, S., Bickelhaupt, R.E., "Joint US/USSR Test Program for Reducing Fly Ash Resistivity", Journal of the APCA, Vol. 29, No. 6, June 1979.

Abstract:

An electrostatic precipitator preceded by a wet scrubber was tested at the Reftinskaya Power Station. The unit collects a high resistivity fly ash from the combustion of low sulfur Ekibastuz coal. The operating parameters of the precipitator were measured as well as the mass emissions and the in-situ electrical resistivity of the fly ash. Density, particle size distribution, electrical resistivity, and chemical composition were determined for collected samples of the fly ash. The fly ash was also characterized by X-ray diffraction and scanning electron microscopy. When a centrifual wet wall scrubber was installed ahead of the electrostatic precipitator, the temperature of the flue gas entering the precipitator was decreased and the moisture content increased. The electrical resistivity of the fly ash was attenuated a decade, but not enough to overcome the adverse effects of back corona in the precipitator. Lowering the flue gas temperature to about 85°C by the addition of a venturi scrubber ahead of the centrifugal scrubber reduced the electrical resistivity of the fly ash another decade and allowed the operation of the precipitator without back corona.

32. Kukin, I., "Advances In The Use Of Chemical Treatment In Air Pollution Reduction Programs", Presented at the National Petroleum Refiners Association Rocky Mountain Region Meeting, Billings, MT, October 2-3, 1968, Paper RM-68-80.

Abstract:

Extensive in-plant tests were made on the ability of a fuel additive containing 25% activated manganese to keep boiler fireside tubes clean and to reduce the sulfur trioxide content of the flue gas. Expecially good results were obtained in a pressurized furnace of 2500 psig when low sulfur fuel oil (one percent) was burned. After three months, the treated furnace showed a 75% reduction in the SO_3 content of the flue gas and only slight tar deposits were apparent. The deposits could be brushed off rapidly, even by simple air lancing. Since the additive is a true in-flame catalyst, it can be applied in much smaller quantities than is the ash with magnesium oxide additives. The manganese additive is not stoiciometrically consumed in reactions with vanadium and sulfur oxides but regenerates itself. It reacts with carbons and hydrocarbons to increase the carbon dioxide content of the flue gas; it further lowers the ignition temperature of combustible deposits within a furnace. By eliminating soot, it improves the appearance of stacks. Another factor favoring the use of the additive is that it reduces the excess air to fuel ratio.

33. Kukin, I., "Additives Can Clean Up Oil-Fired Furnaces", Environmental Science Technology 1973, Vol. 7, No. 7, July 1973.

Abstract:

The addition of metal-containing additives to improve boiler cleanliness, cut fireside and air heater corrosion, and to reduce stack emissions and plumes is discussed. In general, fuel additives should provide boiler cleanliness, high-temperature vanadium corrosion protection, prevention of loss of operating capacity by maintaining design steam temperature, cold end (air heater) corrosion protection, reduction of stack emissions from hydrogen particulate matter and sulfur trioxide, and improvement in the handling characteristics of ash in the flue gas in oil fired boilers equipped with precipitators and stack collectors. The significant fuel additives in use today usually contain magnesium oxide (with or without small amounts of aluminum oxide or hydrate), manganese, and magnesium oxide with manganese. The characteristics of each of these additives is discussed, and the efficacy of magnesium oxide additives is compared to that of manganese additives. Handling characteristics and air emissions are also reviewed.

34. Kukin, I., "Effects of Additives On Boiler Cleanliness and Particulate Emissions", Procurement Int. Meet. Soc. Eng. Sci., 1st, Tel Aviv, Israel, 1972.

Abstract:

Concentrated metal-containing additives are often used in oil-fired furnaces to improve boiler cleanliness and reduce the fireside and air heater corrosion. They can also reduce stack emissions, especially hydrocarbon particulates and sulfur trioxide. They can improve the handling characteristics of the ash in the flue gas in oil-fired boilers equipped with precipitators and stack collectors. Significant fuel additives in use today contain magnesium oxide, manganese, or magnesium oxide with manganese. The role of MgO as a fuel oil additive with high sulfur and high vanadium fuels is described. Low sulfur-low vanadium fuels often contain manganese additives. High temperature slagging and corrosion in oil-fired boilers is reduced with a slurry containing both MgO and Mn in combination. Manganese additives reduce internal boiler fouling of superheaters and reheaters at low ash input ratios. High sulfur fuels with low Vanadium content are preferably treated with tail end chemical injection of an active neutralizing agent to remove SO_3. Overall decrease in stack emission ideally is obtained with a dual additive application consisting of addition of Mn to the fuel oil and a neutralizing agent to the economizer outlet. Manganese additives eliminate stack smoke, particularly in refineries burning pitch or polymerized bottoms. Corrosion and fouling from SO_3 in coil-fired units can be eliminated by aspirating an activated neutralizing agent in powder form into the economizer outlet of the furnace. Other uses of additives are discussed.

35. Kukin, I., Bennett, R., "Chemical Control of Particulate Emissions Through Flue Gas Conditioning", Presented at 12th Conference on Air Quality Management in the Electric Power Industry, The University of Texas at Austin, TX, January 28-30, 1976.

Abstract:

This paper shows how the use of chemicals has become a valuable, relatively simple and quickly installed method for helping coal burning units to meet emissions regulations. Faced with uncertain fuel supplies and handicapped by a capital shortage, the electric utility industry can look to increased use of sophisticated chemical technology for solutions to pollution problems. The proper application of chemical additives can allow utilities to meet emission standards related to particulates and plume opacity, at the same time often allowing for improved efficiency and reduced fuel usage.

36. Kukin, I., Nelson, H., "The Economics of Chemical Conditioning for Improved Precipitator Performance", Public Util. Forth, September 23, 1976.

Abstract:

The result of power companies switching from over 2% sulfur content coal to low sulfur coal has frequently been a reduction of electrostatic precipitator efficiency, resulting in particulate emissions exceeding limits. Chemical treatment can bring the resistivity of fly ash to the level required for high efficiency operation of the electrostatic precipitator. The multifunctional systems capable of optimizing fly ash resistivity, flue gas space charge, and fly ash particle size distribution are the most effective. Case histories illustrate the ability of these chemical systems to obviate the need for multimillion dollar precipitator retrofits. Further benefits are to be expected in new plant designs, where savings in capital and operating costs of chemically treated fly ash permit use of smaller, lower cost electrostatic precipitators.

Flue gas-fly ash conditioning systems do not contribute sulfur oxides to stack gases.

37. Lederman, P.B., Bibbo, P.P., Bush, J., "Sodium Conditioning Aids Precipitation", Presented at Symposium on the Transfer and Utilization of Particulate Control Technology, University of Denver, CO, 24-28 July 1978.

Abstract:

Gas conditioning to aid precipitation of high resistivity particulate has become an accepted method of solving difficult collection problems. Until recetnly, SO_3 was the standard used in cold precipitators. There was no acceptable conditioning method for hot precipitators. Within the past two years, Research-Cottrell has developed sodium conditioning as an alternative for cold precipitators and as a method of choice for aiding hot precipitator operation.

The development of this technology encompassed laboratory studies, pilot tests and field demonstration for a nine-month period. Commercial installations of sodium conditioning systems utilizing several process schemes are in operation.

This paper discusses the laboratory methodology and pilot tests which lead to the adoption of sodium conditioning.

Laboratory results comparing this type of conditioning to others are presented.

The commercial applications are discussed with general flow plans and typical results. Emissions have been reduced by about 90% and opacity has dropped from 60-80% to less than 20% in commercial units using sodium conditioning.

Economics for sodium conditioning are sensitive to the particular operating scheme and coal utilized. General economics will be presented showing that sodium conditioning is a competitive process for difficult fuels and fuel switching situation. Operating costs as low as 0.012 cents per KWH can be expected.

38. Lederman, P.B., Bibbo, P.B., Bush, J., "Chemical Conditioning of Fly Ash for Hot-Side Precipitation", Symposium on the Transfer and Utilization of Particulate Control Technology, EPA 600/7-79-044a, February 1979.

Abstract:

The concerns over universal application of hot precipitators to certain low alkali, low sulfur western coals, which emerged when performance problems on a few installations in the west were encountered (Columbia, Comanche, Hayden), have now been eliminated with the development of practical and proven hot precipitator conditioning technology. Sodium conditioning has been proven in the field as the chemical modifier of choice for hot precipitators. It is economically attractive compared to other means of upgrading marginal precipitators. This technology should be considered for new units to provide conditioned precipitator units capable of operating on difficult ashes with the added benefit of some SO_x removal, at lower costs than systems not utilizing chemical conditioning.

39. Locklin, D.W., Krause, H.H., Reid, W.T., Anson, D., Dimmer, J.P., "Fireside Additive Trials in Utility Boilers--Overview of an EPRI Survey", Combustion, February 1980.

Abstract:

This paper is based on results from EPRI Research Project RP-1035-1. It assembles the available information and reviews the functions and the effects of known fireside additives, by primary chemical constituents, as used in utility boilers firing residual oil and coal. It also presents this information in a form that can be used by utilities as a guide for making decisions regarding the use of fireside additives to combat specific problems.

40. Martin, G.B., D.W. Pershing, and E.E. Berkau, "Effects of Fuel Additives on Air Pollutant Emissions from Distillate-Oil-Fired Furnaces", Environmental Protection Agency, Research Triangle Park, NC, Office of Air Programs, Pub-AP-87, June 1971.

Abstract:

The use of fuel additives to control air pollution from distillate-oil-fired systems was examined. The additives tested were commercially available, proprietary formulations; each additive was analyzed for chemical composition and was screened for effect on emission characteristics. Fewer than 10% of the additves affected any pollutant reduction, whereas more than 20% increased emissions of at least one pollutant. In a few cases, metallic additives substantially reduced particulate emissions, but produced a high concentration of metal compounds in the flue gas. Additives did not reduce emissions of carbon monoxide, unburned hydrocarbons, sulfur oxides, or nitrogen oxides.

41. McRanie, R.D., J.M. Craig, and G.O. Layman, "Evaluation of Sample Conditioners and Continuous Stack Monitors for the Measurement of Sulfur Dioxide, Nitrogen Oxides, and Opacity in Flue Gas from A Coal-Fired Steam Generator", Southern Services, Inc., Birmingham, AL, Research Department, February 1975.

Abstract:

The effectiveness of sample conditioners and continuous stack monitors for the measurement of sulfur dioxide, nitrogen oxides, and opacity in flue gas from a coal-fired steam generator is reported. Individual evaluations of the seven sample conditioners, nine SO_2 analyzers, nine NO_x analyzers, and two opacity monitors included are presented. Analyzer accuracy and sample conditioner influence testing formed an integral part of the evaluation. Reliable and accurate continuous stack monitoring systems cannot be purchased off the shelf from any manufacturer. They must be specified to sample conditioner recommended for use on a coal-fired steam generator. It seems to have no effect on the components of interest in flue gas. The analyzers determined to be most satisfactory with the SSI sample conditions for SO_2 are DuPont, Mine Safety Appliances, and Beckman; for NO_x Thermo Electon and DuPont, and for opacity Lear Siegler. Design and operation recommendations for a monitoring system are included and the analytical techniques used in continuous stack monitoring are discussed.

42. Midkiff, L.A., "Flue-Gas Conditioning Upgrades Performance, Cuts Down Size of Precipitators", Power Vol. 123, No. 4, April 1979.

Abstract:

Chemical enhancement of precipitator efficiency, once limited to low-sulfur retrofit applications, is now being designed into new units. Flue gas conditioning techniques their mechanisms and uses are described. Flue gas conditioning began with the use of moisture to lower ash resistivity. Today's techniques, however, include modification of particle size, and of the space charge in the gas phase. Hot-side as well as cold-side precipitators can often benefit from flue gas treatments that are properly applied. Flyash with a resistivity of 10^9-10^{10}ohm-cm is considered ideal for collection. Methods of lowering the resistivity of the dust, such as the use of a hotside precipitator, or chemical conditioning in the cold-side precipitator, are discussed. Low-resistivity conditioning and space-charge conditioning are finally described.

43. Morris, E.B. and J.L. Schumann, "Condition Flyash with Synthetic SO_3", Power, Vol. 118, No. 7, July 1974.

Abstract:

The conditioning of fly ash with synthetic sulfur trioxide is discussed. It enables an electrostatic precipitator to achieve normal collection efficiencies when cleaning flue gas from boilers burning low sulfur, high ash coals. The injection of minute quantities of SO_3 reduces the electrical resistivity of the fly ash to values below the critical level of 10^{10} ohms-cm. These SO_3 quantities range from 10 to 30 ppm by volume of the flue gas. On site synthesis eliminates the need for storing or handling either sulfuric acid or liquid SO_3. It is more economical than installing new hot precipitators, wet scrubbers, or special low temperature electrostatic precipitators designed for low sulfur coal. Existing plants can upgrade the collection efficiency of their electrostatic precipitators to meet new particulate codes while continuing to burn economical low sulfur coal.

44. Oglesby, S., Jr., Nichols, G.B., "Electrical Resistivity and Conditioning (Chapter 7)", Electrostatic Precipitation, Marcel Dekker, Inc., New York, 1978.

Abstract:

Electrical resistivity of the dust influences electrostatic precipitators (ESP's). If the dust has high resistivity in a single stage precipitator, the corna current will be limited, reducing precipitator performance. The force holding the dust layer to the collecting plant can be large with high resistivity dust, and high intensity rapping is required. Such conditions can result in larger than normal reentrainment. High electrical resistivity of the dust can result in sparkover or back corona. Increased thickness of the dust layer can cause a change from a back corona to a sparking condition for the same dust. The variations in current are such that the maximum allowable current is approximately a decade lower than predicted from theoretical considerations. Volume resistivity and temperature are inversely related at high temperatures. Surface conduction, occurring at lower temperatures, depends upon gaseous reaction with the particles and the composition and morphology of the particles. Conduction above about 250°C is controlled by an ionic mechanism and related to the alkali metals in the ash. Surface resistivity is governed principally by the potassium or sodium and lithium ion concentration. Empirical relationships are given for determining the surface resistivity of ashes. Hot precipitators operate at 600-800°F, where the resistivity is usually low enough that precipitator electrical conditions are not severely limited by breakdown of the dust layer. However, about 50% greater gas volume must be handled. Dust resistivity can be altered changing the ash or flue gas composition. Moisture conditioning, sulfur trioxide conditioning, ammonia additions, and other conditioning agents are discussed.

45. Patterson, R., Riersgard, R., Parker R., Sparks, L.E., "Flue Gas Conditioning Effects on Electrostatic Precipitators", Symposium on the Transfer and Utilization of Particulate Control Technology, EPA-600/7-79-044a, February 1979.

Abstract:

Flue gas conditioning agents are used primarily for maintaining high particulate collection efficiency in electrostatic precipitators operating on high resistivity fly ash from low sulfur coals. Burning low sulfur coals has been a popular method for meeting sulfur dioxide emissions limits. Flue gas conditioning is rarely designed into a new installation; rather, it is normally used as a corrective method for an ailing precipitator.

Many conditioning agents have been investigated for improving the collection efficiency of ESP's. When injected, the conditioning agents mix with the gas to form various gaseous and particulate compounds, depending on the flue gas composition and temperature. This program is designed to determine the improvement in ESP performance and the additional gaseous and particulate compounds which penetrate the ESP.

46. Patterson, R.G., Riersgard, P., Parker, R., Calvert, S., "Effects of Conditioning Agents on Emissions from Coal-fired Boilers: Test Report No. 1", EPA-600/7-79-104a, April 1979.

Abstract:

A field performance test has been conducted on an electrostatic precipitator (ESP) which uses sulfur trioxide as the conditioning agent. The ESP is located at an electric utilities power plant, burning approximately 1% sulfur coal.

Tests were conducted with and without injection of the conditioning agent. The ESP performance was characterized in terms of particle collection efficiency and the chemical composition of particulate and gaseous emissions. Fly ash resistivity and duct opacity were also measured.

Results show an average increase in overall efficiency from 80% to 95% with injection of the conditioning agent. This is accompanied by a decrease in fly ash resistivity, a decrease in opacity, and an increase in sulfur trioxide concentration entering and leaving the precipitator.

47. Patterson, R.G., Long, J., Parker, R., Calvert, S., "Effects of Conditioning Agents on Emissions from Coal-fired Boilers: Test Report No. 2", EPA-600/7-79-104b, April 1979.

Abstract:

A field performance test was done on an electrostatic precipitator (ESP) which uses Apollo Chemical Company's LPA 445 and LAC 51B flue gas conditioning agents. The ESP is located at an electric utilities power plant, burning approximately 1 to 2% sulfur coal.

Tests were conducted with and without injection of the conditioning agents. The ESP performance was characterized in terms of particle collection efficiency and the chemical composition of particulate and gaseous emissions. Fly ash resistivity and flue gas opacity were also measured.

Measurements indicate that there was no significant change in overall penetration (0.4%) between the conditioned and unconditioned tests. There was some evidence that the conditioning agents reduced reentrainment during electrode rapping and possible improved the fractional collection efficiency slightly for particles smaller than about 5 um diameter.

48. Paulson, C.A., Potter, E.C., Kahanne, R., "New Ideas on Precipitation Technology from the Csiro Combustion Rig", Presented at the Changing Technology of Electrostatic Precipitation Symposium, 1974.

Abstract:

A pilot scale coal burning electrostatic precipitation rig is described and its use for assessing the precipitation behavior of fly ash is explained. A method of plotting dust collection efficiencies against a combined function of specific collection area and applied voltage has been developed, which yields a performance line for the precipitator handling a given dust under stated conditions of temperature and carrier gas composition. The performance lines permit the comparison of the precipitation behavior of fly ashes from different coals, and are useful in assessing flue gas additives and in estimating the design size of full scale precipitators from pilot plant observations. The additives investigated include ammonia, sulfur trioxide, trimethylamine, triethylamine, and cyclohexylamine. The performance lines show that triethylamine at trace levels improves precipitator performance dramatically with difficult fly ashes, the improvement being due to agglomeration of suspended dust and raising of breakdown voltage. Some other additives, particularly cyclohexylamine, worsen precipitator performance by lowering breakdown voltage and dispersive natural dust agglomerates.

49. Pressey, R.E., Osborn, D., Cole, E., "Flue Gas Conditioning at Arizona Public Service Company Four Corners Unit No. 4", Symposium on the Transfer and Utilization of Particulate Control Technology, EPA-600/7-79-044a, February 1979.

Abstract:

A Flue Gas Conditioning Program was implemented between March 22, 1977 and July 22, 1977. The objective was to evaluate the effects of Apollo Chemical Corporation's LPA-40 on precipitator performance and emissions.

During the test period, the usual operating problems were encountered. Apollo personnel were given the task of using EPA Method 5 to determine emission rates and recommend adjustments and optimization of flow rates. During the time frame of May 17 through 23, the flow rate was increased from 0.10 to 0.15 gal/ton with a corresponding reduction in emissions. At this point, the unit developed high pressure differential across the preheater. The conditioning agent was changed from LPA-40 to LPA-445. After additional testing and review, it was determined that the differential pressure was increasing again. At this point, the decision was made to test the precipitator's performance with LPA-445 being injected at a rate of 0.10 gal/ton and follow up with performance testing without additives. Test results by Apollo indicated a steady operation with desirable results.

Results of the D.R.I. conditioning tests were determined by measuring mass loading, integrated average and real-time particle size distribution, flue gas composition, temperature, velocity and oxygen profiles and precipitator performance. The test was separated into two phases; one with conditioning and one without. The phases were one month apart.

Chemical and physical analyses were performed to determine the composition of the conditioning agent, its decomposition products and both the coal and ash composition.

50. Petersen, H.H., "Conditioning of Dust with Water-Soluble Alkali Compounds", Symposium on the Transfer and Utilization of Particulate Control Technology, EPA-600/7-79-044a, February 1979.

Abstract:

A comparison of resistivity measurements and chemical analyses of dusts from cement rotary kilns has shown a close relationship between resistivity and the content of water-soluble alkali compounds. Laboratory experiments comprising impregnation of high resistivity dust samples with various water-soluble alkali salts confirmed that small quantities of alkali compounds were sufficient to reduce the resistivity considerably. This led to full scale experiments at a precipitator installation treating high resistivity dust from a preheater kiln at a cement plant in Brazil. Here an aqueous solution of potassium sulfate was injected, atomized and evaporated in the gas stream before the precipitator. An 0.4% increase in water soluble K_2O reduced the resistivity of the dust from 10^{13} to 10^{11} ohm-cm and a corresponding improvement in precipitator performance was observed. Recent additional full scale conditioning experiments with potassium sulfate and sodium chloride at a precipitator installation after a coal-fired lime kiln in South Africa yield similar results.

51. Radway, J.E., "Effectiveness of Fireside Additives in Coal-Fired Boilers", Power Engineering, April 1978.

Abstract:

Benefits of using fireside additives in coal-fired boilers are discussed. A case history is also presented. In addition to aiding emission control and providing for greater flexibility in coal use, chemical treatment may improve operating reliability and increase boiler availability.

52. Roehr, J.D., "Flue Gas Conditioning Cold and Hot Precipitators", Presented at the Southeastern Electric Exchange Meeting, New Orleans, Louisiana, April 16-18, 1980.

Abstract:

This paper discusses the reasons for using flue gas conditioning, the various methods and agents used and the expected operating cost. Several agents or chemicals have been used to achieve conditioning, such as ammonia, water, sodium, sulfuric acid, etc. Proprietary compounds are on the market and are also being used. Some of these conditioning alternatives are outlined here.

53. Saponja, W., "A Systematic Approach to the Application of Electrostatic Precipitators on Low Sulfur Coals," Presented at the Canadian Electrical Association Thermal and Nuclear Power Section, Edmonton, Alberta, October 9, 1974.

Abstract:

Pilot plant field tests were conducted on the fly ash removal capabilities of two identical electrostatic precipitators installed at two coal-fired steam plants using low ranked sub-bituminous coal with an average sulfur content of 0.2-0.23%. At one of the plants, fly ash was readily precipitated with the electrostatic pilot operation, while at the other plant highly resistive fly ash resulted in a serious reduction of effective migration velocity. Flue gas conditioning with sulfur trioxide (just upstream of the pilot precipitator) at the latter plant enhanced the precipitation characteristics of the fly ash particles, and relatively stable electrical conditions were still evident a day after injection had ceased. A sulfur trioxide concentration of 20-25 ppm by volume was adequate. Hot side testing was performed to

evaluate the proposed installation of hot precipitators at the second plant location. A reasonable range for effective migration velocity for a full scale precipitator is 0.30 to 0.37 ft/sec. High resistivity and back-corona are encountered at temperatures under about 600°F.

Sodium conditioning of the high resistance coal used at one location also reduced resistivity but was not economically competitive with gas conditioning.

54. Schliesser, S.P., "Sodium Conditioning Test With EPA Mobile ESP", Symposium on the Transfer and Utilization of Particulate Control Technology, EPA-600/7-79-044a, February 1979.

Abstract:

The objective of this pilot program was to determine the conditioning effects of adding anhydrous sodium carbonate into a "cold-side" slipstream with respect to the collection performance of an electrostatic precipitator (ESP). A power plant combusting low sulfur, low sodium western coal generated the high resistivity ash (2.5×10^{12} ohm-cm @ 270°F) for conditioning evaluation.

A performance evaluation was conducted on a pilot scale precipitator which treated the base and sodium-conditioned flyash. The program, conducted over several weeks, consisted of twenty days of operating and testing. For each ash species, the pilot precipitator treated 28.3 m^3/min (1,000 acfm) of flue gas at an average of 110°C, maintaining a specific collection area equal to 57 m^2/m^3/sec.(290 ft^2/cfm).

In situ resistivity measurements, precipitator operating conditions, and particulate concentration and size distribution measurements constitute the data assembled for the comparative demonstration.

55. Schliesser, S., "Pilot Demonstration of Sodium Carbonate Conditioning", EPA-600/7-79-107, April 1979.

Abstract:

This report describes a performance evaluation, conducted with a pilot precipitator, studying the effects of injecting anhydrous sodium carbonate to the exhaust of a utility boiler burning Western coal.

In situ resistivity measurements, precipitator operating conditions, particulate concentration and size distribution measurements, and analyses of flyash composition constitute the data assembled from this demonstration. The following results reflect the effects of conditioning the base flyash with a 1-2% concentration as sodium oxide:

1. a sixfold reduction in resistivity (i.e., from 2.1×10^{12} to 3.7×10^{11} ohm-cm);

2. a threefold improvement in average current density, (i.e., from 6 to 18 nA/cm^2);

3. a threefold reduction in emission rate, significant enough to move performance from non-compliance (52.4 nanograms/joule) to compliance (15.5 nanograms/joule); and

4. an enhancement in the fractional efficiency characteristics, particularly in the fine particle range.

The characteristics of sodium carbonate conditioning are discussed, including the injection considerations, material specifications, and the distinctive rationale for resistivity reduction.

56. Schwarz, R.C., "Superior Fuel Oil Additives Carry Good Engineering Credentials", National Engineering, Vol. 76, No. 8, August 1972.

Abstract:

The choice of a proper fuel oil additive for the particular problems that beset an individual boiler is a difficult task. Before making a choice, one should know what types of additives are available, what mechanism each uses to function, and possible environmental complications that can result from the use of each. The many additives on the market fall into four general groups: deposition control agents, combustion catalysts, sludge solubilizers, and water emulsifiers. Each of these functions is discussed. Various metal compounds in fuel oil additives include aluminum, barium, copper, lead, magnesium, and manganese. Points worth serious consideration in evaluating an additive supplier are listed. The condensation of sulfur trioxide can cause fouling of the heat recovery elements by a boiler system. Additives can reduce sulfur dioxide conversion to SO_3. Combustion catalysts reduce carbon particulates such as ash in flue gas.

57. Selle, S.J., Hess, L.L., Sondreal, E.A., "Western Fly Ash Composition as an Indicator of Resistivity and Pilot ESP

Removal Efficiency", Presented at the Air Pollution Control Association, Annual Meeting, 68th, Boston, MA, June 15-20, 1975, Paper 75-02.5.

Abstract:

Pilot-scale electrostatic precipitator performance tests were run on a high and low resistivity western fly ash and mixtures thereof. The fly ashes were collected from full-scale electrostatic precipitator hoppers and reentrained in a flue gas of constant analysis ahead of a 120 standard cu ft/min pilot precipitator. Fly ash composition and measured resistivity were good indicators of precipitator performance.

Reentrained high-sodium fly ash acted as an electrostatic precipitator conditioning agent for high resistivity fly ash.

The addition of only 0.75% of the high-sodium fly ash increased the effective migration velocity from 0.5 to 0.8 ft/sec at 300°F. Similar results were obtained at 475°F. Computer regression analysis correlating laboratory fly ash resistivity with chemical analysis substantiated the inverse relationship between resistivity and sodium oxide content of the fly ash.

58. Southern Research Inst., Birmingham, AL, (Editors), "Theoretical and Practical Aspects of Electrostatic Precipitation (Second Quarterly Report)", SORI-EAS-73-017, January 15, 1973.

Abstract:

Field studies involving the use of ammonia vapor to condition flue gas for electrostatic precipitation of fly ash were performed at two Tennessee Valley Authority coal-fired steam plants. The data from both plants, one using low-sulfur coal and the other high-sulfur coal indicated that the mechanism of conditioning was the same at each location. The mechanism consists of a chemical combination of the injected NH_3 vapor with the naturally occurring sulfuric acid vapor in the flue gases to produce small particles of ammonium sulfate.

These small particles are charged in the precipitator, resulting in the enhancement of the space charge, the associated electric field, and ultimately the collection efficiency. The electrical resistivity of the fly ash was unchanged by the addition of NH_3 vapor.

59. Spafford, R.B., Dismukes, E.B., Dillon, H.K., "Analysis of Thermal Decomposition Products of Flue Gas Conditioning Agents", EPA/600/7-79-179, August 1979.

Abstract:

The report gives results of a study of reactions of several flue gas conditioning agents in a laboratory-scale facility simulating conditions in the flue gas train of a coal-burning power plant. Primary purposes of the study were to characterize the chemical species resulting from adding conditioning agents to flue gas and to identify potentially hazardous chemical species originating from the agents that may be emitted into the environment. The compounds investigated were sulfur trioxide, ammonia, triethylamine, sodium carbonate, ammonium sulfate, and diammonium hydrogen phosphate. The predominant types of reactions observed in these experiments were thermal decomposition fragments at lower temperatures, and reactions with normal components of the flue gas. The only significant environmental threat of any product identified during this study was the formation of N-nitrosodiethylamine as the result of injecting triethylamine into the flue gas. This potent carcinogen was found in trace amounts when triethylamine was injected at 160°C.

60. Sparks, L.E., "Electrostatic Precipitators Options for Collection of High Resistivity Fly Ash", Conference on Particulate Collection Problems in Converting to Low Sulfur Coals, EPA-600/7-76-016, October 1976.

Abstract:

An analysis of the technical options for collecting high resistivity fly ash is presented. The options are a large specific collector area at low temperatures (about 150°C), a wet electrostatic precipitator, a moderate to large specific collector area electrostatic precipitator operating at either high (about 370°C) or low temperature (about 110°C), or a moderate specific collector area for an electrostatic precipitator operating at normal temperature with fly ash conditioning. The advantages and disadvantages of each option are discussed. The potential for adverse environmental impact of the conditioning option is also discussed.

61. Sparks, L.E., "Effect of a Flyash Conditioning Agent on Power Plant Emissions", EPA/600/7-76/027, October 1976.

Abstract:

The report gives results of a study undertaken as a preliminary program to provide data on the environmental effects of a chemical flyash conditioning agent (Apollo Chemicals conditioner LPA 402A). Both the emissions due to the chemical and its effect on electrostatic precipitator (ESP) performance were investigated. The tests were conducted over a 10-day period at Pennsylvania Power and Light Company's Montour Plant with the plant operating on high sulfur coal (without conditioner) and on low sulfur coal (with and without conditioner). Sulfur oxides (SO_x), ammonia, organics, particulates, flyash resistivity, and ESP power supply values were measured during each test period. During conditioner injection, the low sulfur coal flyash resitivity was reduced about 60%, although the ESP's responded slowly to this change and its effect was not clearly evident during the test period. The results of the SO_x, ammonia, and particulate measurements were inconclusive due both to insufficient precision for the number of field tests and to the effect of boiler transients. It is unlikely that the ESP will meet particulate standards when low sulfur coal is burned even if the conditioner is used under test conditions. The test provided useful background information for planning. More thorough testing at Montour seems warranted.

62. Steelhammer, J.C., Nogash, D.R., Mangravite, F.J., Graffeo, A.J., Terry, J.P., Harpel, W.L., "Effect of Chemical Additives on Electrostatic Precipitator Performance", Presented at the Purdue Air Quality Conference, Annual, 14th, November 12-13, 1975.

Abstract:

Field evaluations of the effect of various chemical additives on electrostatic precipitator performance were performed. The coal used throughout the experiments contained between 2 and 3% sulfur, 20-25% ash, and 5-7% mixture. The chemical additives were fed to the flue gas as aqueous solutions, and the chemical feed system consisted of several air atomizing spray nozzles. The chemical additives were fed to the flue gas for approximately 1-3 hours before particulate sampling was started. Increases in precipitator collection efficiency were obtained with one organic and two inorganic additives. Efficiencies of 96.4%, 95.3%, and 94,9%, respectively, were obtained with the additives as compared to a control efficiency of 91.9%. The increased efficiencies appeared to be due to space charge effects and cohesivity modification.

63. Tseluiko, Yu. I., Chander, Yu. I., Borisovskii, L.M., "Ammonia Added to the Gas-and-Dust Emission of Rotary Kilns as a Factor in the Performance of the Electrical Precipitators", Refractories, Vol. 16, No. 11-12, November-December 1975.

Abstract:

Electrical precipitators are the most efficient gas scrubbers used in the refractories industry. The degree of dust entrapment by these devices depends on their design and electrical regime and on the properties of the gas and dust mixture emitted by the kiln. The resistivity, i.e., specific electrical resistance (SER), of the dust is a significant factor in the performance of the precipitator. Conditioning the flue gas with ammonia reduces the SER of the dust so that the degree of dust entrapment in electrical precipitators increases, especially when the flue gas contains a large proportion of sulfur oxides. Conditioning is at optimum with a 3-6% ammonia solution and an ammonia consumption of 4-5 kg per 100,000 m^3 flue gas.

64. Watson, K.S., "Australian Experience with Flue Gas Conditioning", Particulate Control in Energy Processes, EPA 600/7-76-010, September 1976.

Abstract:

Australian black coal fired in power stations usually contains less than 1% sulfur and has 15 to 30% ash. Target emission levels for new plants are often better than 0.1 gm/m^3 at NTP requiring collection efficiencies of 99.5%. Highly resistive fly ash predicates specific collecting areas in excess of 80 $m^2/m^3/s$ (400 $ft^2/1000$ cfm) for cold precipitators. Early precipitators frequently had specific collecting areas of less than 50 $m^2/m^3/s$ and performed badly. Gas conditioning has been regularly used to improve collection efficiencies since the middle 60's and to date has been provided on 26 precipitators on boilers from 25 to 500 MW capacity and totalling over 4,000 MW.

Steam and/or water temperature modification, P_2O_5, NH_3, and SO_3 were used experimentally from 1955 onwards. Sulfuric acid was first used operationally in 1964 and anhydrous ammonia has been used since 1965.

65. White, H.J., "Electrostatic Precipitation of Fly Ash: Fly Ash and Furnance Gas Characteristics (Part II, Section 3)", J. Air Pollution Control Association, Vol. 27, No. 2, February 1977.

Abstract:

Fly ash and furnace gas characteristics that affect design and performance of electrostatic precipitators are discussed. The composition, temperature, and pressure of the gas govern the basic corona characteristics of the precipitator, while particle size, particle concentration, and electrical resistivity of the fly ash affect both the corona and the particle collection properties. The gas flow volume rate is also fundamental to precipitator design and performance. The chemical compositions of different kind of coal and of typical furnace gases are present in the precipitator. The presence of sulfur trioxide (SO_3) in the flue gas greatly reduces the electrical resistivity of the fly ash, by raising the dewpoint of the flue gas. Problems of high resistivity can result from the use of low sulfur coals; responses include the location of precipitators ahead of, rather than after, the air preheater, where gas temperatures of 600 to 800°F are sufficiently high to overcome problems of high resistivity. The chemical analysis of fly ash is presented from literature. Particle size distribution of ash from power plants is given. The measurement and significance of particle size and resistivity of fly ash are discussed.

2.3 Specific Installations Using FGC

As mentioned before, many power plants are using FGC to reduce their particulate emissions. Most of the FGC systems have been installed on the already existing ESP's. At present, about 9% of the total MW generated by fossil fuels in the U.S.A. are controlled by FGC. Practically all major utilities have had some experience with gas conditioning.

The bibliography presented in this section deals with specific installations using FGC. Many papers discuss the results of the trial runs or field tests carried out on specific installations. The majority of FGC systems are used on cold side precipitators and on the plants ranging from 40 to 1000 MW.

1. Atkins, R.S., Bubernick, D.V., "Keeping Fly Ash Out of the Stack", Environmental Science and Technology, Vol. 12, No. 6, June 1978.

   Abstract:

   First, two engineers from a company long in the precipitator field explain the functions of these systems, and what some of the design and construction methodology is. Then two other engineers from EPA and a leading research institute tell how they tested a hot-side precipitator, and what they found.

2. Baxter, Walter A., "Recent Electrostatic Precipitator Experience with Ammonia Conditioning of Power Boiler Flue Gases", Journal of the APCA, Vol. 18, No. 12, December 1968.

Abstract:

This paper discusses experiments done by Koppers Company with ammonia conditioning of power boiler flue gases for the purpose of improving the precipitability of the emitted fly ash. Chemical reactions resulting from ammonia injection are postulated. Measurements on three pulverized coal and two cyclone fired boilers, all of which emit acidic ash, are described. In all five cases, considerable but varying, increase in precipitator power input and collection efficiency resulted when gaseous ammonia in the amount of 15 ppm was injected between the economizer and air preheater. The conditioned fly ash showed decreased acidity and inconsistent change in electrical resistivity. Unless air heater temperatures were unusually high (>400°F), the tendency of the air heater to plug was an additional, but unwanted, result. At one station with high air heater outlet temperature, ammonia injection has been adopted as a permanent solution to community pressure for reduction of stack discharge. Ammonia injection downstream of the air heater produced no effect. Future plans are presented to continue the program beyond results described here.

3. Bennett, R.P., "Fly Ash Conditioning to Improve Precipitator Efficiency with Low Sulfur Coals", ASME Publication 76-WA/APC-8, December 1976.

Abstract:

The use of blended chemical agents to condition coal fly ash to improve electrostatic precipitator efficiency and reduce particulate emissions has been subjected to extensive field trials to verify its broad application as a possible economic solution to pollution problems for the electric utility industry. These chemical conditioning agents have been used with a variety of low to medium sulfur coals resulting in precipitator efficiency improvements of 50 to 90 percent. Emissions compliance levels are often obtained as a result of this treatment. The effectiveness of this system has been demonstrated on units from 25 to 750 MW. Case history examples illustrate the types of units treated and the extent of emissions reductions obtained.

4. Bennett, R.P., Kober A.E., "Chemical Enhancement of Electrostatic Precipitator Efficiency", Symposium on the Transfer and Utilization of Particulate Control Technology, EPA-600/7-790044a, February 1979.

Abstract:

It has been shown previously that chemical conditioning of flyash can offer an immediately available alternative to retrofit precipitators, baghouses, or other methods of mechanical collection and usually provides compliance emissions at relatively low operating costs. The equipment required involves minimum capital investment and can usually be installed in a matter of weeks with no significant unit downtime being involved.

It has now been demonstrated that the technique of chemical conditioning can be expanded into a previously untried area with the successful treatment of high-sulfur coals, of hot precipitators, and of low-sulfur coals utilizing a dual-injection system to provide minimum emissions and minimum opacity. Ready availability and minimum total costs are two advantages of this method. The use of new conditioning agents for these processes is continually being examined for further advances in the state of flue gas chemical conditioning.

5. Borsheim, R., "Flyash Conditioning Brings Particulate Emissions Into Compliance", Power Eng., Vol. 81, No. 1, January 1977.

Abstract:

Low sulfur coal has unfavorable consequences on the performance of an electrostatic precipitator. Electrical resistivity of the fly ash, fly ash particle size distribution, and space charge affect the performance of the electrostatic precipitator in a coal-burning power plant. Fly ash conditioning involves injecting an agent into the flue gas, making the fly ash more collectible by the electrostatic precipitator. One commercial additive lowers the electrical resistivity of the fly ash by adsorbing some conductive species on the surface of the particles. When the Corette Power Station started burning coal containing 0.7 to 0.9% sulfur and 8 to 10% ash, the electrostatic precipitator performance was insufficient to meet particulate emission standards at all loads, and the unit was operated up to 16% below its load rating in order to comply. Mechanical and electrical improvements increased efficiency somewhat, but did not permit full-power operation. Opacity was measured constantly. Pre-trial testing in the 148 to 150 MW range gave opacity readings between 30 and 40%. Opacity levels dropped to 15 to 18% within 4 hours after the start of treatment. The amount of generation lost by derating was extremely high. Chemical treatment allowed boiler operating loads to be raised from an average of 148 MW to full load without exceeding particulate emissions and plume opacity limits. The cooling system used prior to treatment deprived the unit of combustion air. Cooling is not longer necessary to maximize precipitator performance. Cost of the treatment is less than 40 cent/ton of coal. This technology makes possible high collection efficiencies on existing equipment at modest prices.

6. Borsheim, R., Bennett, R.P., "Chemical Conditioning of Low Sulfur Western Coal", Presented at 39th Annual Meeting, American Power Conference, Chicago, IL, April 1977.

Abstract:

This paper gives the results of conditioning program carried out at Corette plant of Montana Power Company. Chemical conditioning of fly ash allowed boiler operating loads to be raised from an average of 148 MW to full 163 MW net load without exceeding particulate emissions and plume opacity limits.

7. Breisch, E.W., "Method and Cost Analysis of Alternative Collectors for Low Sulfur Coal Fly Ash", Symposium on the Transfer and Utilization of Particulate Control Technology, EPA-600/7-79-044a, February 1979.

Abstract:

Flue gas conditioning in conjunction with a conventionally sized precipitator is shown to be the most cost-effective means of collecting low sulfur coal, high resistivity fly ash. The results obtained with flue gas conditioning are both predictable and dramatic.

A case in point is the experience which Public Service Company of Colorado has had with vendors for their new 99.2% efficient precipitator installation at Arapahoe Station Unit 1. PSCC received bids from a number of vendors for hot side precipitators and for cold side precipitators with and without conditioning. The Specific Collecting Areas proposed ranged from 295 to 334.5 for the hot gas side precipitator. The bids for cold side ranged from an SCA of 688 with no conditioning, down to 279 with conditioning. PSCC chose the conditioned precipitator, and after a year's operation of the combined installation, is placed on the conditioning. PSCC chose the conditioned precipitator and after a year's operation of the combined installation, acarea of flue gas conditioning including eighteen months of operating experience with Apollo Chemical Corporation products, a planned SO_3 injection trial, and other potential agents.

Results of ongoing trials of Apollo products at Montour SES on two 750 MW bituminous coal fired units are presented. Performance data, operating problems and cost information are covered. Eight chemical formulations have been injected into various combinations of four locations in efforts to improve product performance, solve air heater plugging problems, and improve distribution of the product on the fly ash. A significant reduction of emissions on a difficult fly ash has been noted although only half as great a reduction as originally expected based on tests run with a good collecting fly ash. Air heater plugging problems have been eliminated.

The report also covers some of the practical considerations and potential problems that can occur in evaluating proprietary additives.

Also, the report briefly summarizes projects on six of the Company's ESP's including work in the following areas: fuel quality effects; flue gas conditioning; rappers; voltage controls; sectionalizing; gas flow distribution; operation and maintenance; and additional dust collector capacity.

10. Cook, R., Trykoski, M., "Sulfur Trioxide Injection at State Line Station", EPA-600/7-76-016, October 1976.

Abstract:

Commonwealth Edison's efforts to overcome the problem of electrostatic precipitator degradation through the use of sulfur trioxide (SO_3) flue gas conditioning is described. An analysis of the coal (low sulfur) being burned in Edison boilers revealed that the coal fly ash, with its higher resistivity, reduces the current flow between the electrodes of the electrostatic precipitator, and therefore the precipitator performance is reduced when compared to operation on high-sulfur coal. Evaluation of the Edison generating system showed that a total of 22 precipitators on ten generating units ranging in size form 120 to 620 MW would suffer degradation while burning low sulfur coal to the point where they could no longer meet particulate emission standards while operating at full load. Flue gas conditioning was sought as a means of restoring precipitator efficiency through the lowering of fly ash resistivity. Test results showed a dramatic improvement in precipitator performance with flue gas conditioning. Problems related to startup and miscellaneous boiler and precipitator effects are noted. Flue gas conditioning systems have not alleviated the other operating problems associated with the burning of low sulfur coal, but they are enabling these units to meet particulate emission standards with minimal derating at a cost far less than that of the only other feasible alternatives, major precipitator rebuild or a new precipitator.

11. Cook, R.E., "Sulfur Trioxide Conditioning", J. Air Pollution Control Association, Vol. 25, No. 2, February 1975.

Abstract:

Burning of western low sulfur coal, to reduce sulfur oxide emissions, has resulted in decreased electrostatic precipitator collection efficiencies. In an effort to restore precipitator performance a flue gas conditioning program was established. This paper discusses experience with sulfur trioxide as a flue gas conditioning agent. Testing at State Line Station has proven that sulfur trioxide conditioning can effectively be used to improve precipitator performance when burning low sulfur coals.

12. Dismukes, E.B., "Conditioning of Fly Ash With Ammonia", Journal of the APCA, Vol. 25, No. 2, February 1975.

Abstract:

This paper presents the results of an investigation of the conditioning of fly ash with ammonia in electrostatic precipitators of power plants operated by the Tennessee Valley Authority. It focuses attention primarily on the mechanisms of conditioning encountered under the particular circumstances available for study. No effect of ammonia on the electrical resistivity of fly ash was evident. Instead, the effect of ammonia appeared to be an enhancement of the space-charge component of the electric field used for charging and precipitating particles of fly ash. In addition, a second effect appeared to be an increase in the cohesiveness of precipitated ash and a reduction in the quantity of ash reentrained during electrode rapping. Data demonstrating the value of ammonia conditioning for lowering the emission of fly ash during three precipitator studies are presented. Reasons for the ineffectiveness of ammonia conditioning during a fourth precipitator study are discussed. In conclusion, comments are made about the effects to be expected from ammonia conditioning under circumstances different from those investigated experimentally, particularly with ammonia as a conditioning agent for fly ash from low sulfur Western coal.

13. Dismukes, E.B., Gooch, J.P., "Fly Ash Conditioning With Sulfur Trioxide", EPA/600/2-77/242, December 1977.

Abstract:

The report describes an evaluation of an SO_3 injection system for the George Neal Unit 2 boiler of the Iowa Public Service Company in Sioux City, Iowa. Results of base line tests without conditioning indicate a dust resistivity of 6 x 10 to the 12th power ohm-cm at 118°C; the precipitator's average collection efficiency was 91.3% at a specific collecting area of 42.8 $m^2/(m^3/sec)$. Because transformer-rectifier sets tripped out, apparently due to ash buildup in the hoppers, only one precipitator efficiency test was conducted with SO_3 system operating continuously with all T-R sets operating. Results of this test were: (1) specific collecting area = 41.8 $m^2/(m^3/sec)$; (2) collection efficiencies = 99.27% (ASME method), 98.96% (EPA method), and 98.78% (EPA method, including first impinger residue); and (3) 4 x 10 to the 10th power ohm-cm dust resistivity at 143°C. An adequate accounting was made for the fate of the injected SO_3.

14. Engel, W. and M. Meyerkord, "Flue Gas Conditioning at Wisconsin Power & Light to Improve Hot-side Precipitator Performance", Presented at the Seventh Annual Technical Conference of the Air Pollution Control Association, Midwest Section, Kansas City, Missouri, May 22-23, 1980.

Abstract:

To meet emission standards for sulfur dioxide, an increasing number so power plants have turned to western low-sulfur coal. While this has several technical and economic advantages, the fly ash released upon burning these coals is unfavorable in certain installations for adequate collection by electrostatic precipitators (ESPs). Reasons for this unfavorable performance have been related to high electrical resitivity fo the fly ash and relatively high proportion of small particle fly ash.

The cold side precipitator is still the most common means of particulate collection, especially for plants constructed before the early "70s. Hot-side precipitators are designed to eliminate the problem of high fly ash resistivity. The concept of the hot-side ESP was based on the correlations observed between sulfur content in coal, flue gas temperature, and fly ash resistivity. Fly ash resistivity drops sharply at elevated temperatures. Placement of the precipitator prior to the air heater where gas temperatures are typically 600-800^{o}F, helps to overcome the resistivity problems. Many precipitators perform adequately in this mode. Certain low-sulfur coals, however, continue to produce a fly ash chemistry detrimental to precipitator operation, despite the higher flue gas temperature.

This phenomenon was experienced when Wisconsin Power & Light Company's Columbia Station Unit #1 went on line in the latter half of 1975. WP&L planners designed the unit around utilization of low-sulfur western coal, selecting hot-side electrostatic precipitation as the means fo controlling fly ash emissions.

Chemical flue gas conditioning, a technology that has been effective in upgrading the efficiency of cold side electrostatic precipitators, has been successfully developed to overcome fly ash collection problems on hot-side ESPs. Known commercially as the Coaltrol HPC system, this new flue gas conditioning system for hot-side precipitators has been applied at Columbia Station, enabling the plant to continue to comply with opacity and emission requirements.

15. Ferrigan, J.J., III, and J.D. Roehr, "SO_3 Conditioning for Improved Electrostatic Precipitator Performance Operating on Low Sulfur Coal," Proceedings of the Symposium on the Transfer and Utilizaton of Particulate Control Technology, Denver, Colorado, 1979.

Abstract:

This presentation deals with a case study of a particular utility's dilemna of having to choose an efficient and reliable air pollution control device to lower stack emissions on an existing unit. The paper traces the study from the time when excessive emissions required MW load deratings into the decision making process, the testing stage, and finally into the installation of SO_3 flue gas conditioning.

It points out why, in this particular case, SO_3 flue gas conditioning is a more reasonable choice than the installation of a new cold side precipitator or fabric filter baghouse. It clearly shows via test results supplied by a utility based in upstate New York that SO_3 flue gas conditioning enables units at their power plant to operate well within the legal standards enforced by the New York State Department of Environmental Conservation (NYSDEC).

16. "Flue Gas Conditioning", Environment Science and Technology, Vol. 12, No. 13, December 1978

Abstract:

Low sulfur coals are increasingly used because of stringent air pollution control restrictions on sulfur oxide emissions. However, low sulfur coals can present other problems, such as flyash that is hard to capture using an electrostatic precipitator. One solution to this problem is to inject a chemical into the flue gas to condition the flyash. Some recent developments indicate that full federal acceptance of the flue gas conditioning technology may not be too far off. Representative Paul Rogers (D-FLA) has requested that EPA investigate chemical conditioning with the possible goal of requiring flue gas treatment under authority granted the agency under the Clean Air Act of 1977. Several instances of the use of flue gas conditioning by U.S. companies are described.

17. Green, G.P., "Operating Experience with Particulate Control Devices", Presented at the American Society of Mechanical Engineers, Air Pollution Control Division, National Symposium, 3rd, Philadelphia, PA, April 1973.

Abstract:

Operating experience associated with the control of particulate emissions from steam plant units burning low sulfur, high resistivity, western coals is reviewed. Initially disappointing collection efficiencies with electrostatic precipitators were improved by conditioning the flue gas with sulfur trioxide such that its concentration in the gas to be treated was 20 ppm. Collection efficiencies for eight different units ranged from 37.5-94.0% before flue gas conditioning and from 51.2-97.2% after conditioning with SO_3.

18. Green, G.P., Landers, W.S., "Operating Experience With Gas Conditioned Electrostatic Precipitators", United States-USSR Working Group, Stationary Source Air Pollution Control Technology, Control Fine-Part., Emiss. Ind. Sources Symposium Proc., San Francisco, CA, 1974, January 15-18, Paper 8.

Abstract:

The effect of flue gas conditioning on the fly ash collection efficiency of eight electrostatic precipitators installed on pulverized coal burning units of the Public Service Company of Colorado is reported. The addition of 15-20 ppm of sulfur trioxide directly to the flue gas before the electrostatic precipitator increased collection efficiencies from a range of 37.5-94.0% for the eight units prior to gas conditioning to a range of 51.4-96.2%. The low efficiencies prior to SO_3 treatment were due to the high resistivity of the untreated fly ash (10 to the 13 ohm-cm) which in turn was due to the fact that the plant burns low sulfur western coal. Gas conditioning did not compensate for design deficiencies other than the resistivity problem.

19. Jaworowski, R.J., O'Connor, M.J., "Effect of Flue Gas Conditioned Fly Ash on Electrostatic Precipitator Control", Procurement of the ISA Conference and Exhibition, Philadelphia, PA, October 15-19, 1978.

Abstract:

Electrostatic precipitators (ESP) are designed for a specific combination of dust fineness, resistivity, and concentration. The ability of the ESP to cope with changes in these parameters is limited and significant reductions in performance often accompany changes in coal supplies (high sulfur coal to low sulfur coal to reduce SO_2 emissions). This paper discusses the use of precipitator control readings to diagnose problems resulting from changes in fly ash resistivity, particle size distribution, and concentration. The use of chemical conditioning agents to overcome the adverse effects of these changes is discussed and examples of successful applications are given.

20. Kukin, I., Bennett, R., "Chemical Control of Particulate Emissions Through Flue Gas Conditioning", Presented at 12th Conference on Air Quality Management in the Electric Power Industry, The University of Texas at Austin, TX, January 28-30, 1976.

Abstract:

This paper shows how the use of chemicals has become a valuable, relatively simple and quickly installed method for helping coal burning units to meet emissions regulations. Faced with uncertain fuel supplies and handicapped by a capital shortage, the electric utility industry can look to increased use of sophisticated chemical technology for solutions to pollution problems. The proper application of chemical additives can allow utilities to meet emission standards related to particulates and plume opacity, at the same time often allowing for improved efficiency and reduced fuel usage.

21. Kukin, I., Bennett, R., "Particulate Emission Control Through Chemical Conditioning", Combustion Vol. 48, No. 4, October 1976.

Abstract:

The chemical treatment of flue gases to reduce polluting emissions was subjected to quantitative field tests to verify its practicality as a possible economic solution to current energy and pollution problems for electric utilities. Chemical conditioning agents for the ash in the flue gas improved electrostatic precipitator collection efficiency by 50-90%, so that the units complied with emission regulations. Some units have been able to operate at increased capacity while still meeting compliance levels.

22. Lederman, P.B., Bibbo, P.B., Bush, J., "Chemical Conditioning of Fly Ash for Hot-Side Precipitation", Symposium on the Transfer and Utilization of Particulate Control Technology, EPA 600/7-79-044a, February 1979.

Abstract:

The concerns over universal application of hot precipitators to certain low alkali, low sulfur western coals, which emerged when performance problems on a few installations in the west were encountered (Columbia, Comanche, Hayden), have now been eliminated with the development of practical and proven hot precipitator conditioning technology. Sodium conditioning has been proven in the field as the chemical modifier of choice, for hot precipitators. It is economically attractive compared to other means of upgrading marginal precipitators. This technology should be considered for new units to provide conditioned precipitator units capable of operating on difficult ashes, with the added benefit of some SO_x removal, at lower costs than systems not utilizing chemical conditioning.

23. Locklin, D.W., Krause, H.H., Reid, W.T., Anson, D., Dimmer, J.P., "Fireside Additive Trials in Utility Boilers--Overview of an EPRI Survey", Combustion, February 1980.

Abstract:

This paper is based on results from EPRI Research Project RP-1035-1. It assembles the available information and reviews the functions and the effects of known fireside additives, by primary chemical constituents, as used in utility boilers firing residual oil and coal. It also presents this information in a form that can be used by utilities as a guide for making decisions regarding the use of fireside additives to combat specific problems.

24. Patterson, R.G., Riersgard, P., Parker, R., Calvert, S., "Effects of Conditioning Agents on Emissions from Coal-fired Boilers: Test Report No. 1", EPA-600/7-79-104a, April 1979.

Abstract:

A field performance test has been conducted on an electrostatic precipitator (ESP) which uses sulfur trioxide as the conditioning agent. The ESP is located at an electric utilities power plant, burning approximately 1% sulfur coal.

Tests were conducted with and without injection of the conditioning agent. The ESP performance was characterized in terms of particle collection efficiency and the chemical composition of particulate and gaseous emissions. Fly ash resistivity and duct opacity were also measured.

Results show an average increase in overall efficiency from 80% to 95% with injection of the conditioning agent. This is accompanied by a decrease in fly ash resistivity, a decrese in opacity, and an increase in sulfur trioxide concentration entering and leaving the precipitator.

25. Patterson, R.G., Long, J., Parker, R., Calvert, S., "Effects of Conditioning Agents on Emissions from Coal-fired Boilers: Test Report No. 2", EPA-600/7-79-104b, April 1979.

    Abstract:

    A field performance test was done on an electrostatic precipitator (ESP) which uses Apollo Chemical Company's LPA 445 and LAC 51B flue gas conditioning agents. The ESP is located at an electric utilities power plant, burning approximately 1 to 2% sulfur coal.

    Tests were conducted with and without injection of the conditioning agents. The ESP performance was characterized in terms of particle collection efficiency and the chemical composition of particulate and gaseous emissions. Fly ash resistivity and flue gas opacity were also measured.

    Measurements indicate that there was no significant change in overall penetration (0.4%) between the conditioned and unconditioned tests. There was some evidence that the conditioning agents reduced reentrainment during electrode rapping and possible improved the fractional collection efficiency slightly for particles smaller than about 5 um diameter.

26. Paulson, C.A.J., Potter, E.C., Kahane, R., "New Ideas On Precipitation Technology From The Csiro Combustion Rig",

Presented at the Changing Technology of Electrostatic Precipitation Symposium, 1974.

Abstract:

A pilot scale coal burning electrostatic precipitation rig is described and its use for assessing the precipitation behavior of fly ash is explained. A method of plotting dust collection efficiencies against a combined function of specific collection area and applied voltage has been developed, which yields a performance line for the precipitator handling a given dust under stated conditions of temperature and carrier gas composition. The performance lines permit the comparison of the precipitation behavior of fly ashes from different coals, and are useful in assessing flue gas additives and in estimating the design size of full scale precipitators from pilot plant observations. The additives investigated include ammonia, sulfur trioxide, trimethylamine, triethylamine, and cyclohexylamine. The performance lines show that triethylamine at trace levels improves precipitator performance dramatically with difficult fly ashes, the improvement being due to agglomeration of suspended dust and raising of breakdown voltage. Some other additives, particularly cyclohexylamine, worsen precipitator performance by lowering breakdown voltage and dispersive natural dust agglomerates.

27. Pressey, R.E., Osborn, D., Cole, E., "Flue Gas Conditioning at Arizona Public Service Company Four Corners Unit No. 4", Symposium on the Transfer and Utilization of Particulate Control Technology, EPA-600/7-79-044a, February 1979.

Abstract:

A Flue Gas Conditioning Program was implemented between March 22, 1977 and July 22, 1977. The objective was to evaluate the effects of Apollo chemical Corporation's LPA-40 on precipitator performance and emissions.

During the test period, the usual operating problems were encountered. Apollo personnel were given the task of using EPA Method 5 to determine emission rates and recommend adjustments and optimization of flow rates. During the time fram of May 17 through 23, the flow rate was increased from 0.10 to 0.15 gal/ton with a corresponding reduction in emissions. At this point, the unit developed high pressure differential across the preheater. The conditioning agent was changed from LPA-40 to LPA-445. After additional testing and review, it was determined that the differential pressure was increasing again. At this point, the decision was made to test the precipitator's performance with LPA-445 being injected at a rate of 0.10 gal/ton and follow up with performance testing without additives. Test results by Apollo indicated a steady operation with desirable results.

Results of the D.R.I. conditioning tests were determined by measuring mass loading, integrated average and real-time particle size distribution, flue gas composition, temperature, velocity and oxygen profiles and precipitator performance. The test was separated into two phases; one with conditioning and one without. The phases were one month apart.

Chemical and physical analyses were performed to determine the composition of the conditioning agent, its decomposition products and both the coal and ash composition.

28. Petersen, H.H., "Conditioning of Dust with Water-Soluble Alkali Compounds", Symposium on the Transfer and Utilization of Particulate Control Technology, EPA-600/7-79-044a, February 1979.

Abstract:

A comparison of resistivity measurements and chemical analyses of dusts from cement rotary kilns has shown a close relationship between resistivity and the content of water-soluble alkali compounds. Laboratory experiments comprising impregnation of high resistivity dust samples with various water-soluble alkali salts confirmed that small quantities of alkali compounds were sufficient to reduce the resistivity considerably. This led to full scale experiments at a precipitator installation treating high resistivity dust from a preheater kiln at a cement plant in Brazil. Here an aqueous solution of potassium sulphate was injected, atomized and evaporated in the gas stream before the precipitator. An 0.4% increase in water soluble K_2O reduced the resistivity of the dust from 10^{13} to 10^{11} ohm-cm and a corresponding improvement in precipitator performance was observed. Recent additional full scale conditioning experiments with potassium sulphate and sodium chloride at a precipitator installation after a coal-fired lime kiln in South Africa yield similar results.

29. Saponja, W., "A Systematic Approach to the Application of Electrostatic Precipitators on Low Sulphur Coals", Presented at the Canadian Electrical Association Thermal and Nuclear Power Section, Edmonton, Alberta, October 9, 1974.

Abstract:

Pilot plant field tests were conducted on the fly ash removal capabilities of two identical electrostatic precipitators installed at two coal-fired steam plants using low ranked sub-bituminous coal with an average sulfur content of 0.2-0.23%. At one of the plants, fly ash was readily precipitated with the electrostatic pilot operation, while at the other plant highly resistive fly ash resulted in a serious reduction of effective migration velocity. Flue gas conditioning with sulfur trioxide (just upstream of the pilot precipitator) at the latter plant enhanced the precipitation characteristics of the fly ash particles, and relatively stable electrical conditions were still evident a day after injection had ceased. A sulfur trioxide concentration of 20-25 ppm by volume was adequate. Hot side testing was performed to evaluate the proposed installation of hot precipitators at the second plant location. A reasonable range for effective migration velocity for a full scale precipitator is 0.30 to 0.37 ft/sec. High resistivity and back-corona are encountered at temperatures under about 600°F.

Sodium conditioning of the high resistance coal used at one location also reduced resistivity but was not economically competitive with gas conditioning.

30. Schliesser, S., "Pilot Demonstration of Sodium Carbonate Conditioning", EPA-600/7-79-107, April 1979.

Abstract:

This report describes a performance evaluation, conducted with a pilot precipitator, studying the effects of injecting anhydrous sodium carbonate to the exhaust of a utility boiler burning Western coal.

In situ resistivity measurements, precipitator operating conditions, particulate concentration and size distribution measurements, and analyses of flyash composition constitute the data assembled from this demonstration. The following results reflect the effects of conditioning the base flyash with a 1-2% concentration as sodium oxide:

1. a sixfold reduction in resistivity (i.e., from 2.1 x 10^{12} to 3.7 x 10^{11} ohm-cm);
2. a threefold improvement in average current density, (i.e., from 6 to 18 nA/cm^2);
3. a threefold reduction in emission rate, significant enough to move performance from non-compliance (52.4 nanograms/joule) to compliance (15.5 nanograms/joule); and
4. an enhancement in the fractional efficiency characteristics, particularly in the fine particle range.

The characteristics of sodium carbonate conditioning are discussed, including the injection considerations, material specifications, and the distinctive rationale for resistivity reduction.

31. Southern Research Inst., Birmingham, AL, (Editors), "Theoretical and Practical Aspects of Electrostatic Precipitation (Second Quarterly Report)", SORI-EAS-73-017, January 15, 1973.

Abstract:

Field studies involving the use of ammonia vapor to condition flue gas for electrostatic precipitation of fly ash were performed at two Tennessee Valley Authority coal fired steam plants. The data from both plants, one using low sulfur coal and the other high sulfur coal indicated that the mechanism of conditioning was the same at each location. The mechanism consists of a chemical combination of the injected NH_3 vapor with the naturally occuring sulfuric acid vapor in the flue gases to produce small particles of ammonium sulfate.

These small particles are charged in the precipitator, resulting in the enhancement of the space charge, the associated electric field, and ultimately the collection efficiency. The electrical resistivity of the fly ash was unchanged by the addition of NH_3 vapor.

32. Sparks, L.E., "Effect of a Flyash Conditioning Agent on Power Plant Emissions", EPA-600/7-76-027, October 1976.

Abstract:

The report gives results of a study undertaken as a preliminary program to provide data on the environmental effects of a chemical flyash conditioning agent (Apollo Chemicals conditioner LPA 402A). Both the emissions due to the chemical and its effect on electrostatic precipitator (ESP) performance were investigated. The tests were conducted over a 10-day period at Pennsylvania Power and Light Company's Montour Plant with the plant operating on high sulfur coal (without conditioner) and on low sulfur coal (with and without conditioner). Sulfur oxides (SO_x), ammonia, organics, particulates, flyash resistivity, and ESP power supply values were measured during each test period. During conditioner injection, the low sulfur coal flyash resistivity was reduced about 60%, although the ESP's responded slowly to this change and its effect was not clearly evident during the test period. The results of the SO_x, ammonia, and particulate measurements were inconclusive due both to insufficient precision for the number of field tests and to the effect of boiler transients. It is unlikely that the ESP will meet particulate standards when low sulfur coal is burned even if the conditioner is used under test conditions. The test provided useful background information for planning. More thorough testing at Montour seems warranted.

33. Steelhammer, J.C., Nogash, D.R., Mangravite, F.J., Graffeo, A.J., Terry, J.P., Harpel, W.L., "Effect of Chemical Additives on Electrostatic Precipitator Performance", Presented at the Purdue Air Quality Conference, Annual, 14th, November 12-13, 1975.

Abstract:

Field evaluations of the effect of various chemical additives on electrostatic precipitator performance were performed. The coal used throughout the experiments contained between 2 and 3% sulfur, 20-25% ash, and 5-7% mixture. The chemical additives were fed to the flue gas as aqueous solutions, and the chemical feed system consisted of several air atomizing spray nozzles. The chemical additives were fed to the flue gas for approximately 1-3 hours before particulate sampling was started. Increases in precipitator collection efficiency were obtained with one organic and two inorganic additives. Efficiencies of 96.4%, 95.3%, and 94,9%, respectively, were obtained with the additives as compared to a control efficiency of 91.9%. The increased efficiencies appeared to be due to space charge effects and cohesivity modification.

34. Watson, K.S., "Australian Experience with Flue Gas Conditioning", Particulate Control in Energy Processes, EPA-600/7-76-010, September 1976.

Abstract:

Australian black coal fired in power stations usually contains less than 1% sulfur and has 15 to 30% ash. Target emission levels for new plants are often better than 0.1 gms/m^3 at NTP requiring collection efficiencies of 99.5%. Highly resistive fly ash predicates specific collecting areas in excess of 80 m^2/m^3/s (400 ft^2/1000 cfm) for cold precipitators. Early precipitators frequently had specific collecting areas of less than 50 m^2/m^3/s and performed badly. Gas conditioning has been regularly used to improve collection efficiencies since the middle 60's and to date has been provided on 26 precipitators on boilers from 25 to 500 MW capacity and totalling over 4,000 MW.

Steam and/or water temperature modification, P_2O_5, NH_3, and SO_3 were used experimentally from 1955 onwards. Sulfuric acid was first used operationally in 1964 and anhydrous ammonia has been used since 1965. Triethylamine was first used in 1975 and is currently being evaluated.

The effect of reagents varies from station to station and is also dependent on precipitator type and reagent concentration. Considerable care must be given to the injection system to allow proper mixing and sufficient residence time. Improvements of migration velocity in excess of 300% have been attained with SO_3/H_2SO_4 and in excess of 200% with ammonia, which is the preferred reagent because of its relative safety and convenience. Triethylamine appears to be even more effective than SO_3.

Comparatively few operational problems have been reported and most can be traced to over-conditioning or to poor distribution. Capital costs range from 0.05 to 0.12 $/KW and operating costs from 0.01 to 0.05 mils/KW-hr depending on the reagent and injection concentration.

2.4 Legal and Regulatory Aspects

There is not much literature on the regulatory aspects of using FGC. "Enforcement Policy on Interim Particulate Controls (Guidance)" developed recently by DOE is the only document that deals with the regulatory aspects and again, it applies to only those power plants that are out of compliance with particulate emission regulations.

On the legal side, many suppliers have obtained patents for their conditioning methods using specific chemicals. The patents are listed and described below.

Patents

1. Patent No. 3,568,403
Title: Removal of Solids from Flue Gas
Filed June 21, 1966
Author: Harry L. Richardson, Pittsburgh, Pennsylvania
Assignor to: Chemical Construction Corporation, New York, NY

Description:

Improve electrostatic precipitation of entrained solids from flue gas, which is generated by burning sulfur-containing solid carbonaceous fuel, is attained by burning a vandium-containing liquid hydrocarbon such as high vandium content crude oil or refinery residual oil together with the solid fuel. The vanadium which is thus added to the combustion process is converted to vandium pentoxide which causes at least partial catalytic oxidation of sulfur dioxide to sulfur trioxide, which provides improved results and greater efficiency during subsequent treatment of the flue gas by electrostatic precipitation, in terms of greater solids removal from the flue gas.

2. Patent No. 3,689,213
Title: Process for Treating Flue Gases
Filed February 19, 1970
Author: Salvatore A. Guerrieri

Description:

Liquid sulfur dioxide is vaporized and admixed with an excess of compressed and dehumidified oxygen-containing gas. The mixture is introduced into a converter wherein the sulfur dioxide is converted to sulfur trioxide. The gaseous products from the converter are introduced into a flue gas, produced by the combustion of a low sulfur, solid fossil fuel, prior to the passage thereof through electrostatic precipitator means.

3. Patent No. 3,686,825
Title: Electro-Precipitation
Filed May 18, 1970
Author: Howard G. T. Busby, Solihull, England
Assignor to: Lodge-Cottrell Limited, Birmingham, England

Description:

An injection assembly for injecting SO_3 conditioning agent into a duct carrying gas to be cleaned to an electro-precipitator comprises a manifold extending across the duct and a plurality of elongated nozzles extending from the manifold. Each nozzle and associated structure presents an aerofoil configuration of controlled dimensional parameters so that optimum aerodynamic conditions are obtained for the SO_3 injection.

4. Patent No. 3,993,429
Title: Gas Conditioning Means
Filed May 7, 1975
Author: William E. Archer, Huntington Beach, California
Assignor to: Wahlco, Inc., Santa Ana, California

Description:

A method of preconditioning a boiler fuel gas mixture containing fly ash for the efficient removal of the fly ash by electrostatic precipitation comprising the steps of: directing at least a portion of a flow of air into a sulfur burner; directing sulfur into said sulfur burner; combusting said sulfur within said sulfur burner to create a fluid mixture including the the combustion products of said sulfur; detecting the temperature of said fluid mixuture exiting from said sulfur burner; selectively varying the quantity of said portion of said directed flow of air in response to said detecting; passing said fluid mixture through a catalytic converter to produce a conditioning mixture; and combining said conditioning mixture with said flue gas mixture prior to passing said flue gas mixture into an electrostatic precipitator.

5. Patent No. 4,043,768
Title: Method of Conditioning Flue Gas to Electrostatic Precipitator
Filed April 5,1976
Authors: Robert P. Bennett, Bridgewater, New Jersey
Matthew J. O'Connor, Flanders, New Jersey
Assignors to: Apollo Chemical Corporation, Whippany, New Jersey

Description:

A method of improving the collection characteristics of particles entrained in a stream of particle-laden gas formed by the burning of coal for collection by an electrostatic precipitator, comprising forming a mixture

a. the particle-laden gas at a temperature of 590-900°C, and

b. finely divided ammonium bisulfate; and mixture containing 75-1,250 grams and ammonium bisulfate per metric ton of coal burned to form said gas, and

c. after forming said mixture, directing said gas stream through a heat exchange means and into an electrostatic precipitator to collect said particles therein.

6. Patent No. 4,058,372

Title: Flue Gas Conditioning with Spiking Gas Containing Sulfur Trioxide

Filed June 22, 1976

Author: George B. DeLaMater, Media, Pennsylvania

Assignor to: Air Products and Chemicals, Inc., Allentown, Pennsylvania

Description:

In a process for removing fly ash from flue gas at a temperature of from about 140°C to about 160°C by

a. treating the flue gas with a spiking gas containing sulfur trioxide in a sufficient amount for conditioning the flue gas in a mixing zone, and then

b. precipitating the fly ash from the flue gas by electrostatic means, the improvement which comprises:

   1. forming a spiking gas containing from about 0.15 to 1.2 mol percent sulfur trioxide, and
   2. maintaining the spiking gas at a temperature sufficiently high between a temperature of from about 300° to about 750°C such that on treating the flue gas with the spiking gas, the temperature of any mixture of spiking gas and flue gas from the point of introduction to the point of dilution as determined by the equation.

7. Patent No. 4,042,348

Title: Method of Conditioning Flue Gas to Electrostatic Precipitator

Filed August 2, 1976

Authors: Robert P. Bennett, Bridgewater, New Jersey
Matthew J. O'Connor, Flanders, New Jersey
Alfred E. Kober, Hopatcong, New Jersey
Ira Kukin, West Orange, New Jersey
Assignors to: Apollo Chemical Corporation, Whippany, New Jersey

Description:

A method of improving the collection characteristics of particles entrained in a stream of particle-laden gas formed by the burning of coal for collection by an electrostatic precipitator, comprising forming a mixture of:

a. the particle-laden gas at a temperature of 590°-900° C., and
b. Finely divided ammonium sulfate; said mixture containing 75-1250 grams of ammonium sulfate per metric ton of coal burned to form said gas, and
c. after forming said mixture, directing said gas stream through a heat exchange means and into an electrostatic precipitator to collect said particles therein.

8. Patent No. 4,070,162
Title: Method of Agglomerating Particles in Gas Stream
Filed August 2, 1976
Authors: Alfred E. Kober, Hopatcong, New Jersey
Ira Kukin, West Orange, New Jersey
Assignors to: Apollo Chemical Corporation, Whippany, New Jersey

Description:

A method of conditioning a particle-laden gas comprising the step of forming a mixture of the particle-laden gas and a conditioner comprising finely divided urea, said mixture being at a temperature of at least 150°C, said conditioner being present in an amount sufficient to produce agglomeration of said particles.

9. Patent No. 4,070,424

Title: Method and Apparatus for Conditioning Flue Gas With a Mist of Sulfuric Acid

Filed September 21, 1976

Authors: Wallace I. Olson
Robert H. Gaunt
Jerome G. Lynch

Assignors to: UOP Inc.

Description:

Method of injecting an acid conditioning agent into a flue gas stream containing fly ash to be conditioned to enhance the efficiency with which the fly ash can be electrostatically precipitated comprising the steps of:

- passing sulfuric acid conditioning agent under pressure through a first line into a lance incorporating a sonic atomizing nozzle;

- heating a portion of said first line adjacent said lance so that said acid will be heated to a temperature higher than ambient but lower than its vaporizing temperature and which is sufficient to increase its temperature to at least about 93°C before it leaves the nozzle; and

- Passing a gas under pressure through a second line into said nozzle, said gas pressure being at least about 10 psig higher than the liquid acid pressure, and said nozzle incorporating means to produce sonic vibrations capable of breaking up said liquid acid into a mist having a mean droplet size no greater than about 10 microns.

10. Patent No. 4,113,447

Title: Method of Conditioning Flue Gas

Filed May 2, 1977

Authors: Robert P. Bennett, Bridgewater, New Jersey
Alfred E. Kober, Hopatcong, New Jersey

Assignors to: Apollo Chemical Corporation, Whippany New Jersey

Description:

A method of conditioning a particle-laden gas formed by the burning of coal comprising forming a mixture of:

a. the particle-laden gas at a temperature of 200-900°C, and

b. finely divided sodium bisulfate; said mixture containing 75-1250 grams of sodium bisulfate per metric ton of coal burned to form said gas;

and thereafter passing the mixture through an electrostatic precipitator.

11. Patent No. 4,123,234

Title: Alkanol Amine Phosphate for Improving Electrostatic Precipitation of Dust Particles

Filed December 12, 1977

Author: Peter H. Vossos, Lisle, Illinois

Assignor to: Nalco Chemical Company, Oak Brook, Illinois

Description:

In a method of improving the conductivity of particles entrained in a stream of particle-laden gas formed by the burning of coal, which particles are collected by an electrostatic precipitator *the improvement of which* comprises treating said gas containing particles prior to contact with the electrostatic precipitator at a temperature not greater then about 650°F, with a sufficient amount of resistivity-decreasing an alkanol amine phosphate.

12. Patent No. 4,141,697

Title: Alkaline Treated Molecular Sieves to Increase Collection Efficiency of Electrostatic Precipitators

Filed January 9, 1978

Author: Vincent M. Albanese, Lockport, Illinois

Assignor to: Nalco Chemical Company, Oak Brook, Illinois

Description:

A method of improving the conductivity of particles entrained in a stream of particle-laden gas formed by the burning of coal, which particles are collected by an electrostatic precipitator which comprises treating said gas containing the particles prior to contact with the electrostatic precipitator at a temperature not greater than about 1800°F with an amount of a molecular sieve sufficient to decrease resistivity to 10^8-10^{10} ohm-cm, having the formula

$M_{2}/_{w}\ O:Al_2O_3:wSiO_2:YH_2O$

wherein M represents at least one cation which balances the electrovalence of the tetrahedra, n represents the valence of the cation, w the moles of SiO_2 and Y the moles of H_2O and then passing the gas to the electrostatic precipitator.

13. Patent No. 4,177,043

Title: Chemical Treatment for Improving Electrostatic Precipitation of Dust Particles in Electrostatic Precipitators

Filed May 22, 1978

Author: Vincent M. Albanese, Lockport, Illinois

Assignor to: Nalco Chemical Company, Oak Brook, Illinois

Description:

A method of improving the conductivity of fly ash particles entrained in a stream of particle-laden gas formed by the burning of coal, which fly ash particles are collected by an electrostatic precipitator which comprises treating said particles prior to their precipitation in an electrostatic precipitator with a treatment chemical comprising ammonium sulfate plus triethylamine sulfate combined in a weight ratio of 0.5-12:1 said treatment chemical being added at a level of from 0.125-2.0% by weight of the fly ash present in said particle laden gas.

14. Patent No. 4,208,192

Title: Sonic Spray of H_2SO_4 in a Swirling Heated Air Stream

Filed October 27, 1978

Authors: William A. Quigley, Creenwich, Connecticut
Paul H. Sorenson, Fairfield, Connecticut

Assignors to: UOP Inc., Des Plaines, Illinois

Description:

Method of injecting an acid conditioning agent into a flue gas stream containing fly ash to be conditioned to enhance the efficiency with which the fly ash can be electrostatically precipitated comprising the steps of:

a. passing a liquid acid conditioning agent under pressure through a first line into a nozzle at a temperature lower than its vaporizing temperature;

b. passing a gas from a first supply source under pressure through a second line into said nozzle, said nozzle incorporating means to produce sonic vibrations capable of breaking up said liquid acid into a mist plume having an average droplet size of about 10 microns;

c. passing a stream of hot gas from a second supply source having a temperature greater than the vaporization temperature of said liquid acid and of a value of at least about 500^{O}F, tangentially into one end of a cylindrical chamber in which said nozzle holder and nozzle are mounted in such a manner that said stream of hot gas will travel in a helical manner and will entrain and vaporize substantially all of the acid mist plume emanating from said nozzle; and

d. passing the stream of hot gas containing said vaporized acid into said flue gas stream after it has traversed the length of said cylindrical chamber.

15. Patent No. 4,213,767
Title: Electrostatic Precipitation
Filed May 14, 1979
Author: Vincent M. Albanese, Lockport, Illinois
Assignor to: Nalco Chemical Company, Oak Brook, Illinois

Description:

A method of improving the conductivity of particles entrained in a stream of particle-laden gas formed by the burning of coal, which particles are collected by an electrostatic precipitator which comprises treating said gas containing particles prior to contact with the electrostatic precipitator at a temperature not greater than about 800°F, with a resistivity decreasing amount of hexamethylene tetramine or its water soluble salts and thereafter passing the gas to the electrostatic precipitator.